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UNIVERSITY OF ALBERTA

ISOTOPIC AND ELEMENTAL EVIDENCE FOR VARIATION IN DIETARY PATTERNS DURING THE BAIKAL NEOLITHIC

BY

YIN-MAN LAM ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Arts.

DEPARTMENT OF ANTHROPOLOGY

Edmonton, Alberta
Fall, 1993

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ISBN 0-315-88210-7

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DEGREE: Master of Arts

YEAR THIS DEGREE WAS GRANTED: 1993

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "Isotopic and Elemental Evidence for Variation in Dietary Patterns during the Baikal Neolithic" submitted by Yin-man Lam in partial fulfillment of the requirements for the degree of Master of Arts.

Dr. Andrzej Weber

Dr. Owen Beattie

Dr. Nancy Lovell

M L Wayman
Dr. Michael Wayman

28 June 1993

ABSTRACT

In this thesis, the dietary patterns of three prehistoric cultural groups from central Siberia are compared by means of stable isotope ratio and trace element analysis in order to evaluate competing hypotheses concerning the subsistence strategies employed by the Neolithic inhabitants of the Lake Baikal region. The study was conducted on human burial remains from Lokomotiv and Ust'-Ida, two sites in the Upper Angara Valley.

The characteristics and chronological relationship of the Kitoi, Isakovo/Serovo, and Glazkovo cultures have previously been documented by Okladnikov (1950, 1955, 1959, 1964) on the basis of archaeological evidence, of which burial material comprised the predominant component. Okladnikov interpreted the Isakovo/Serovo to be egalitarian hunters, but believed that the Kitoi and Glazkovo displayed a greater degree of social stratification and subsisted primarily by fishing. However, many of the criteria used to classify burials according to cultural affiliation were poorly defined and may have been utilized arbitrarily. Recent research, including the C-14 dating of a number of sites, have effectively repudiated Okladnikov's socio-economic model and chronology for this period. One of these studies -- Goriunova & Vorob'eva (1986) -- presented the hypothesis that the variations in assemblage composition observed during the course of the Baikal Neolithic reflected not changes in subsistence strategies but advances in technology. In sum, this recent research has provided the foundation for a theoretical reassessment of this period in prehistory.

This study contributes to this reassessment by examining dietary variation among the Neolithic cultures in the Angara Valley. The concentrations of eight elements (Ba, Fe, Mg, Mn, Sr, Zn, Ca, and P) were determined for specimens collected from twenty-three adult human skeletons. Stable carbon and nitrogen isotope ratios were obtained for a sample of remains representing twenty-nine individuals.

The results of the trace element analysis suggest the possibility of dietary differences between and within the three cultures but were likely affected by diagenesis. The isotopic data do not distinguish dietary variation due to gender; they do demonstrate significant differences in mean $\delta^{13}C$ and $\delta^{15}N$ values between the Kitoi and the other two cultures. While further research in the Baikal region is integral to the interpretation of these data, the present evidence indicates that the diet and subsistence behavior of the Kitoi differed from those of the Isakovo/Serovo and Glazkovo.

ACKNOWLEDGEMENTS

The completion of this thesis would not have been possible without the assistance of a number of individuals. My expression of gratitude to the people named below is not intended to divert from myself the responsibility for any shortcomings that may become evident in the pages that follow.

I am indebted to my supervisors, Professors Andrzej Weber and Owen Beattie, for their patience, advice, and encouragement, and for presenting me the opportunity to participate in their respective research projects. This thesis is a small contribution to an expansive research program into Siberian prehistory that Dr. Weber is currently conducting.

I thank Harold Krueger for the award of nitrogen and carbon SIRA of 20 specimens at Geochron Laboratories, Cambridge, Massachusetts, and François LaRose for conducting the SPSS analysis of my data. The bone specimens analyzed in this study were provided by A. K. Konopatskii of the Russian Academy of Sciences in Novosibirsk and V. I. Baziliiskii and O. I. Goriunova of Irkutsk State University. The members of my committee, Professors Nancy Lovell and Michael Wayman, offered insightful criticism of a previous draft; Diane Formanski of the Spectral Services Laboratory, Department of Chemistry, ran the ICP-AES; Bob Swindlehurst of the same lab provided welcome advice and assistance; Diane Cockle drew Figure 1.1; Murielle Nagy loaned me her Imagewriter; and Ping Lai supplied references on trace elements.

The Department of Anthropology provided me with two years of financial support in the form of graduate assistantships and three years of moral support in the form of Darlene, Gail, Harvey, Marlys, and Pam. From my first semester at the University of Alberta, Professors Clifford Hickey and Kyril Holden have been tremendously and consistently supportive of my efforts and ambitions. I am grateful for their many kindnesses.

Lastly, I thank my parents for their patience and for their bemused acceptance that their only child may never own a briefcase, a tongue depressor, or more than four neckties.

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CHAPTER ONE -- INTRODUCTION

The Lake Baikal region is one of the few areas of Siberia whose prehistory has been extensively investigated and documented. From the 1930's through the 1950's, the Russian prehistorian A. P. Okladnikov conducted a comprehensive archaeological study of the Neolithic cultures of this region and, until recently, his interpretation of change in subsistence strategies and social organization during this period has been accepted with generally little reservation by Russian and western researchers alike. In the past decade, data from archaeological and osteological studies, as well as the first series of C-14 dates obtained for this region, have contradicted a number of Okladnikov's original conclusions. This new evidence has mandated the formulation of a revised assessment of the Baikal Neolithic. In a preliminary contribution toward this end, the research presented here reexamines Okladnikov's hypothesis of change in subsistence activities and social organization among the Neolithic inhabitants of the Lake Baikal region.

In this thesis, the dietary patterns of individuals belonging to three cultures representing the Neolithic and Eneolithic/Bronze Age of the Lake Baikal region of Siberia are compared by means of stable isotope ratio and trace element analysis. While archaeometric techniques have recently been used to date archaeological sites in Siberia, they have not been applied to the study of the diet, subsistence, and social organization of the prehistoric inhabitants of this region. Siberia contains two-thirds of the world's boreal forest and, unlike North America, many of its regions provide soil conditions conducive to the preservation of organic material. The high level of organic preservation and an abundance of rich burial sites in this vast region offer unprecedented opportunities for the application of archaeometric techniques to paleodemographic and paleodietary research, of which this project represents a pioneering effort.

The remainder of Chapter One discusses traditional and recent archaeological interpretations of the Neolithic period of Lake Baikal and the relevance of this thesis to this area of research. Chapter Two and Chapter Three review the roles of trace elements and stable isotope analysis, respectively, in the reconstruction of prehistoric diet -- their theoretical foundation, previous applications, and inherent limitations. Chapter Four presents the research methodology, Chapter Five the results of the laboratory analysis and a statistical evaluation of the data. Chapter Six summarizes the findings of this analysis and suggests directions for future research.

1.1 The Neolithic of the Lake Baikal Region -- An Overview

By far the world's oldest (20 to 30 million years) and deepest (*c.* 1.65 km), Lake Baikal holds about one-fifth of the earth's fresh water. It is extremely rich in biomass -- due to deep oxygen circulation and heat from hydrothermal vents in certain sections of its floor, life exists through the entire depth of the lake. The lake is a closed ecosystem, with its 344 tributaries originating from surrounding mountains. A reflection of this ecological isolation, the majority of the lake's aquatic species are endemic, and include the nerpa (*Phoca sibirica*), the only species of freshwater seal on earth (Matthiessen, 1992). In contrast to its plethora of tributaries, Lake Baikal has but a single outlet -- the wide and swiftly-flowing Angara River. Rich in archaeological sites, the Angara Valley appears to have attracted human settlement since the Upper Paleolithic, as evidenced by the sites of Arembovskogo, Igeteiskii Log I, Mal'ta, and Buret' (Vasil'ev, 1993).

In the Upper Angara Valley, Neolithic sites are generally located on terraces along a local westerly course of the river, near rapids and/or the confluction of a large tributary. Burial sites are situated on flat areas approximately fifteen to twenty meters higher than the level of the river while habitation sites lie on lower terraces (Michael, 1958). It is likely that a large number of sites on these level terraces have been destroyed by the farming practices of Russian colonists and, more recently, by the construction of dams on the Angara (Okladnikov, 1950).

The term "Neolithic" in Siberian prehistory does not have the customary socio-economic connotations of agriculture and sedentism (Chard, 1974:63). The advent of the

Neolithic in this region is associated with the generally contemporaneous appearance of pottery (Chard, 1974) and the bow and arrow (Okladnikov, 1964). Some ambiguity in the definition of this period may be due to the occurrence of site assemblages which exhibit all the characteristic Neolithic elements with the exception of pottery. Such sites have typically been considered older -- representative of a "pre-ceramic Neolithic" -- without any consistent justification aside from this negative evidence (Chard 1974:59-60). The three cultures examined in this study include the Kitoi, the Isakovo/Serovo, and the Glazkovo, each of which is represented by burial sites along the Upper Angara river. These three cultures comprise the entire Neolithic sequence of the Lake Baikal region.

The traditional view of the Baikal Neolithic, as detailed by Okladnikov in the 1950's, has not undergone any significant revision until very recently. The available English literature on this topic is extremely limited and somewhat obsolete, dating mostly from the late 1950's through the 1960's. Several of these works were biased in their attempt to demonstrate similarities between the Siberian Neolithic and various periods in North American prehistory (e. g., Tolstoy, 1958*a*, 1958*b*; Griffin, 1960). Fortunately, Okladnikov's overview of the Baikal Neolithic has been translated (1959, 1964) and detailed descriptions and evaluations of his work have been presented by western archaeologists (e. g., Michael, 1958; Chard, 1974). In this section, Okladnikov's original interpretation of the Baikal Neolithic is discussed, followed by dissenting viewpoints and recent research in this area.

1.2 Okladnikov's Model of Cultural Evolution

Despite encountering some dissent among his Russian colleagues, the archaeological assessment of the Baikal Neolithic presented by Okladnikov (1950, 1955, 1959, 1964) was accepted with little reservation by western researchers (Michael, 1958; Chard, 1974) and remains basically unchallenged in its scope and persistence. Due to the paucity and sparse distribution of Neolithic habitation sites, as well as the poor documentation of the few that have been studied, Okladnikov's chronology of this period was based entirely on his typological evaluation of evidence from burial sites. During the course of his data collection, which was conducted primarily in the 1930's, Okladnikov recognized three major types of burial complexes in the Angara River Valley -- the Serovo and the Kitoi, both classified as Neolithic, and the Glazkovo, which represents either the transitional late Neolithic ("Eneolithic") or the earliest local Bronze Age culture. A small number of graves with Serovo affinities were classified as belonging to an earlier culture -- the Isakovo. The main characteristics of each culture, as noted by Okladnikov, are described briefly below.

1.2.1 The Isakovo

Isakovo graves were typically filled with limestone slabs and the deceased placed in an extended position, usually with the hands under the body. Most Isakovo graves contain single individuals. Associated artifacts consist most notably of an array of hunting equipment, including bone spear points, flint knives, and numerous stone arrowheads. No bows have been preserved, suggesting that they were non-composite and made solely of wood (Michael, 1958:41). The ceramics of this stage are crude and simple, usually covered with net impressions. Ornamental items include boar's tusk pendants and antler beads.

The Isakovo culture was dated by Okladnikov (1964:29) to approximately 4000 BC, and its characteristics were initially defined by Okladnikov (1950) on the basis of only twelve graves in the Angara valley.

1.2.2 The Serovo

Serovo graves are characteristically lined with stones of uniform size. Most burials contain only one individual, usually in an extended position. No differentiation in grave goods was observed between male and female burials. Burials of both sexes typically include bows and arrows, a variety of stone tools, and ceramic vessels (Michael, 1958:52, 57). A distinguishing feature of this culture is its advanced hunting technology -- including the earliest evidence for composite bone/wood bows in the region. The lithic technology demonstrates similar progress relative to that of the Isakovo, particularly in the mode of retouching (Michael, 1958:45). Fishing equipment, absent among the Isakovo, occurs in a number of Serovo graves and includes hooks, net sinkers, and polished stone figurines carved in the images of different species of fish. The latter may have been used as lures for harpoon fishing (Okladnikov, 1964:30). Ceramics of this period are also more complex than their Isakovo counterparts, with distinct shapes, more elaborate decoration, and, in some cases, handles. Ornamental items include deer and moose tooth pendants and shell beads.

Okladnikov (1964) dated the Serovo to between 4000 and 3000 BC. The presence of bone plates from composite bows is the primary identifying features of Serovo burials (Okladnikov, 1950). On the basis of burial material, he interpreted the Isakovo and the Serovo peoples to have been egalitarian hunters.

1.2.3 The Kitoi

Kitoi graves are characterized by the use of ochre to cover the deceased. Kitoi burials exhibit noticeable variation in the quantity of grave goods, suggesting the presence of social inequalities (Michael, 1958; Okladnikov, 1964). Multiple burials of men and women also occur during this period and were interpreted by Okladnikov (1950) as evidence of complex social relations, the beginning of a transition from a matriarchal to patriarchal society, and, possibly, slavery.

Several different types of arrowheads were recovered but are rare compared to the abundance of fishing equipment, most notably composite "Kitoi" fish hooks, which occur in virtually all burials of this culture. None of the fish figurines characteristic of the Serovo were found in Kitoi burials. The lithic assemblages are dominated by tools made of green nephrite. It should be noted that the type site for this culture is located at the confluction of the Angara and the Kitoi rivers, the latter of which originates in the Sayan Mountains, a major source of this stone (Okladnikov, 1964). Ceramic vessels are generally similar in style to those of the Serovo, but many were decorated using a "stab-and-drag" method unique to this period (Michael, 1958:68). Ornamental objects include boar's tusks and deer tooth beads.

The Kitoi burials examined by Okladnikov provided evidence for a heavy reliance on fishing and possible social stratification. This period was dated to approximately 3000-2000 BC (Okladnikov, 1964). The characteristic features used to identify Kitoi graves were the consistent use of ochre to cover the deceased and the less consistent -- but frequent -- presence of composite fish hooks.

1.2.4 The Glazkovo

The Glazkovo tool inventory includes both hunting and fishing equipment, but Okladnikov (1964:51) suggested that the fishing inventory, organized in satchels and placed in graves, held greater importance within the culture. Glazkovo grave goods consist of early metal artifacts both functional -- such as bronze fish hooks, copper and bronze knives, and copper needles -- and ornamental, including bronze wire bracelets (Michael 1958:10).

The wide variation observed in the content of Glazkovo burials appeared to imply a greater degree of social stratification and sexual division of labor. Most Glazkovo burials contain only a single individual, but in a small number of graves, a male and female are interred together and accompanied by artifacts respectively representative of hunting and domestic activities. Based on such observations, Okladnikov (1964:52) interpreted the Glazkovo to represent a "social advance" -- having completed the transition from a matriarchal to a patriarchal society and having developed hierarchical distinctions based on wealth and gender.

The position and orientation of the interred were important criteria in Okladnikov's distinction between the Glazkovo and the Neolithic cultures. Glazkovo burials typically lie parallel to a river, while the majority of Isakovo, Serovo, and Kitoi burials are oriented east-west along the path of the sun. In Glazkovo graves, the deceased are arranged in a flexed position, while those of the Neolithic cultures lie in an extended position. At certain sites where both Neolithic and Eneolithic burials occur (e. g., Ust'-Ida), it appears that the latter may have been distinguished solely on the basis of their body position in the absence of metal artifacts (A. Weber, pers. comm.).

The Glazkovo culture was dated to 1800-1300 BC by Okladnikov (1964). Glazkovo burials are the oldest in which copper and bronze artifacts have been recovered in the Baikal region. The presence of such metal artifacts and the flexed body position of the interred are the primary features that distinguish Glazkovo burials from those of the earlier Neolithic.

1.2.5 Okladnikov's chronology and model

In Okladnikov's view, the aforementioned differences in burial practices indicated the existence of distinct, sequential cultures and could not simply have reflected the presence of geographically discrete populations or social hierarchies within populations. He observed that burial sites representing each culture were distributed within the same geographic regions (e. g., the Upper Angara). And, as noted above, certain sites such as Ponomarevo and Bratskii Kamen' contained burials from more than one culture. While Okladnikov did suggest that social stratification existed within the later Neolithic cultures, he noted that within each culture, the *types* of goods placed with each interment are generally consistent regardless of age or sex (Okladnikov, 1950). In addition, grave goods did not appear to have been produced specifically for the burials -- they generally consisted of utilitarian items indistinguishable from those found at contemporaneous habitation sites

(Michael, 1958). As a result, Okladnikov believed that it was most reasonable to explain these variations in burial ritual as representative of different chronological periods.

To establish his chronology, Okladnikov compared each of the Neolithic cultures with the Eneolithic/Bronze Age Glazkovo. On the basis of artifact assemblages, he determined that the Kitoi exhibited the greatest affinity to the Glazkovo. The most convincing evidence appeared to be the prevalence of fish hooks in both the Kitoi and Glazkovo burials, particularly in light of their paucity in Serovo graves. A number of other artifacts -- including flint arrowheads with a rounded base, small antler picks, white marble bracelets, and cylindrical perforated beads -- are common to the Kitoi and Glazkovo but absent among the Serovo. A lithic raw material commonly utilized by the Kitoi and Glazkovo was nephrite; the Serovo used predominately slate and chert. Michael (1958:15) suggested that the hypothetically earlier Serovo (and, by implication, Isakovo) people were unable to work the harder, higher quality nephrite. The clay paste used in Kitoi and Glazkovo vessels also exhibit similar characteristics not observed in Serovo ceramics. In Kitoi and Glazkovo burials, grave goods were typically arranged in a small concentration, while in those of the Isakovo and Serovo, they are found distributed around the body. As a result, Okladnikov inferred that the Kitoi culture was the immediate predecessor to the Glazkovo and that the Isakovo and Serovo were more ancient.

Given the increasing forestation and the concomitant decrease in the abundance of large gregarious herbivores during the Pleistocene/Holocene transition, Okladnikov's interpretation of a shift in emphasis from hunting among the Isakovo and Serovo to fishing among the Kitoi and Glazkovo during the Neolithic appeared to correlate, if somewhat belatedly, with the documented change in available resources (Chard, 1974). In addition, Okladnikov claimed to document the evolution of social stratification through time. Among the Isakovo and Serovo, there exists little variation in the quantity and quality of grave goods between individuals. In fact, it was specifically noted that, among the Serovo, both men and women were buried with similar hunting equipment (Okladnikov, 1964; Michael, 1958:52). In contrast, Kitoi grave goods vary significantly in content, and by the Glazkovo period, burial material appears to reflect status differences and an established sexual division of labor (Okladnikov, 1964). As a whole, Okladnikov's proposed sequence for the Baikal Neolithic corresponded with expected trends toward increasing social complexity and adaptations toward subsistence in a forested environment.

Despite a number of challenges, Okladnikov's model for the Baikal Neolithic has persisted for the past half-century for one primary reason: contradictory views presented by other researchers were typically based on single lines of investigation (e. g., anthropometric features, pottery styles, etc.); none of their studies approached the scale of Okladnikov's comprehensive synthesis of a wide range of archaeological evidence. In addition, Okladnikov's dominant status as an academician may have discouraged both contemporary and subsequent researchers from voicing dissenting viewpoints (A. Weber, pers. comm.).

1.3 Alternative Assessments of the Baikal Neolithic

As discussed above, Okladnikov's chronology of the Baikal Neolithic illustrated changes in subsistence strategy and advances in technology accompanied by an increase in social complexity, a view remarkably consistent with the universal assessment of the Neolithic throughout the Old World. Subsequent research (discussed below) has raised questions concerning Okladnikov's conclusions and called attention to a number of shortcomings in the archaeological methodology he employed during the course of his studies. Okladnikov's philosophical adherence to the classic unilinear evolutionism that formed the theoretical foundation of Russian archaeology may have resulted in his selective, rather than systematic, examination of the archaeological evidence. The majority of data collection was conducted before the Second World War and thus did not incorporate the many methodological advances adopted in recent decades by western archaeologists. Quantitative presentation and statistical analysis of data were virtually absent from Russian archaeological research during this period. Site sampling and excavation appeared to have been executed in a subjective manner, without the assistance of basic recovery procedures such as sieving and floatation. In addition, data were often presented selectively. For example, of the 74 Glazkovo graves known to Okladnikov, he (1950) documented the contents of only nineteen. Of this sample, each grave produced metal artifacts. In more recent studies, copper and bronze objects have not been consistently recovered from Glazkovo graves; cultural attribution was often based upon flexed body positioning and orientation parallel to a river.

Okladnikov's socioeconomic model of the Baikal Neolithic was undoubtedly biased by its reliance on data from burial sites and concomitant failure to incorporate the limited, but potentially significant, data from settlement sites. Among the documented habitation sites in this region, Kitoi components never occur in conjunction with Isakovo/Serovo assemblages, although both are found in association with (and underlying) Glazkovo material. Mesolithic levels have been encountered immediately beneath Kitoi deposits (Georgievskaia, 1989). As a result, Okladnikov's chronology could not be correlated with (nor fully discredited by) documented stratigraphic relationships.

Okladnikov's assessment of the Baikal Neolithic has been disputed by a small number of contemporary and subsequent researchers. In particular, Gerasimov (1955) found, based on the analysis of craniometric data, that the Kitoi people were morphologically distinct from the other Neolithic peoples, with the latter exhibiting more pronounced Mongoloid features. He suggested that the Kitoi predated the other Neolithic cultures and that the Isakovo and Serovo were a single people. Mamonova's (1973) study supported Gerasimov's findings, documenting craniometric affinities between Serovo and Glazkovo individuals but statistically significant differences between these groups and the Kitoi. In a more recent study incorporating palynological evidence, Goriunova & Vorob'eva (1986) came to the conclusion that little environmental change occurred during the Baikal Neolithic, leading them to suggest that the differences in artifact assemblage composition observed during the course of this period primarily reflected technological advances rather than the major changes in subsistence strategies proposed by Okladnikov.

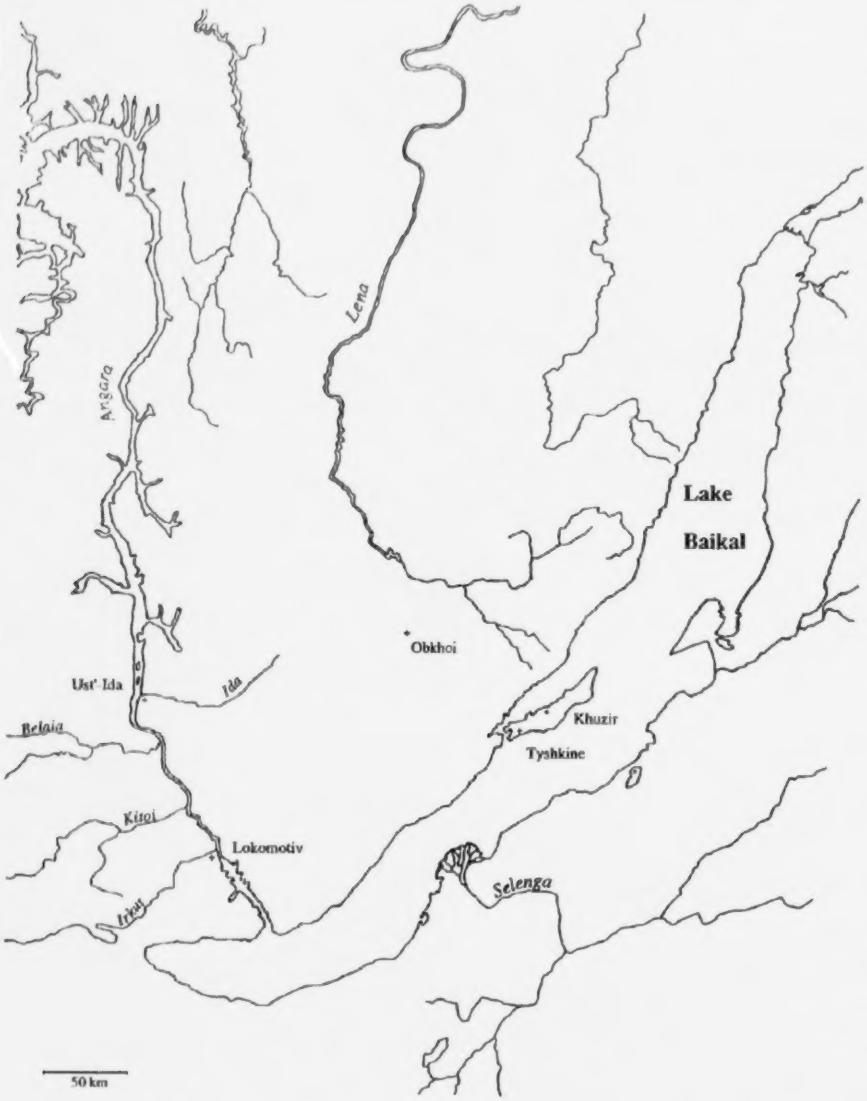
The most unequivocal repudiation of Okladnikov's chronology occurred with the recent C-14 dating of a number of burials belonging to the different Neolithic cultures (Mamonova & Sulerzhitskii, 1989). The Kitoi have been dated as the earliest Neolithic culture, while the Isakovo and Serovo peoples have been determined to be generally contemporaneous (Table 1.1). In light of the paucity of Isakovo graves and the many similarities between them and those of the Serovo, the two have been grouped together as a single, Isakovo/Serovo culture, following Gerasimov's (1955) recommendation. There is an overlap between the temporal ranges of the Serovo and the Glazkovo that may require a reassessment of the relationship between these two cultures. Table 1.1 presents the chronology of the Baikal Neolithic as presented by Okladnikov (1964) and as determined by C-14 dating (Mamonova & Sulerzhitskii, 1989; V. I. Baziliiskii, pers. comm.).

	Typological Chronology	Carbon-14 Chronology
Isakovo/Serovo	4000-3000 BC	4190-3210 BC
Kitoi	3000-2000 BC	5720-5080 BC
Glazkovo	1800-1300 BC	3650-2150 BC

Table 1.1: Typological and C-14 chronologies of the Baikal Neolithic (from Okladnikov, 1964; Mamonova & Sulerzhitskii, 1989; V. I. Baziliiskii, pers. comm.)

In sum, this recently obtained evidence offers a convincing challenge to the traditional view of the Baikal Neolithic. While Okladnikov's chronology has been effectively repudiated, the corresponding model of cultural and economic change he presented has yet to undergo significant revision in the hands of the current generation of Russian archaeologists; an updated, comprehensive reassessment of the Baikal Neolithic remains to be forged. In particular, an alternate model for the evolution of subsistence behavior and social organization has yet to be formulated, and it is hoped that this thesis will contribute toward the remedy of this situation.

Figure 1.1: Location of Neolithic sites sampled for this study



1.4 Examining the Diet of the Peoples of the Baikal Neolithic

The acceptance of a revised chronology for the Baikal Neolithic invites further investigation of the available archaeological evidence. In this pursuit, archaeologists will undoubtedly adopt current archaeometric techniques to supplement the traditional culture-historical approach employed by Russian prehistorians. This thesis applies two such techniques -- stable isotope and trace element analysis of prehistoric human bone -- in order to examine variation in dietary patterns and, by inference, subsistence activities among and within the Kitoi, Isakovo/Serovo, and Glazkovo cultures. Such analyses of bone chemistry have demonstrated certain advantages over archaeological studies of diet based on the examination of artifacts and faunal and floral remains. Due to taphonomic biases, the archaeological record does not preserve a representative sample of the resources utilized by a population, and the dietary importance of particular food items are not necessarily corroborated by their abundance -- or that of the artifacts used to exploit them -- at prehistoric sites. In addition, differential distribution of food resources within populations is difficult to detect by archaeological methods. If the dietary components consumed by a prehistoric population are identified and their chemical composition determined, the application of stable isotope and trace element analysis can, in theory, provide a quantitative estimation of the relative contribution of those components to the diet of any individual within the population. Unfortunately, due to the lack of documentation of the availability and chemical composition of the food resources utilized by the prehistoric inhabitants of Siberia, it is not currently feasible to attempt a systematic and quantitative reconstruction of the diet of these early populations. Nevertheless, these restrictions should not preclude the examination of gross dietary differences between these populations.

For this study, a sample of bones from adult individuals representing all three cultures of the Baikal Neolithic was selected for chemical analyses. The bone specimens were recovered from two burial sites in the Upper Angara Valley. The Kitoi sample was obtained from Lokomotiv, the Isakovo/Serovo and Glazkovo samples from Ust'-Ida

(Figure 1.1). In addition to the human remains, faunal specimens -- representing two seal, two cervids, and a dog -- and a modern sample of cedar nuts (an ethnographically documented food resource for recent inhabitants of Siberia), were analyzed. As exclusive piscivores and herbivores respectively, seals and cervids have diets that should represent two extremes between which the diet of Neolithic peoples should lie. The dog, if a domesticated individual, would have had an omnivorous diet similar to that of its masters. Unfortunately, no prehistoric faunal samples could be obtained from the same sites as the human specimens, nor was it possible to procure modern or prehistoric samples of fish or exclusive carnivores from this region for analysis. It was anticipated that the available faunal data would provide an extremely general framework in which to evaluate the human evidence.

Due to its detail and scope, Okladnikov's original assessment of the Baikal Neolithic currently provides the primary foundation for the formulation of testable hypotheses. Further examination of the *patterns* of economic and social change illustrated by Okladnikov's model is inappropriate due to its recently demonstrated chronological inaccuracy; what requires testing is his association of particular subsistence activities and social structures with specific Neolithic cultures on the basis of mortuary data. In light of Okladnikov's attribution of egalitarianism and a subsistence based on large-game hunting to the Isakovo/Serovo and his association of social stratification, sexual division of labor, and a fishing economy with the Kitoi and Glazkovo, the following hypotheses are considered of particular relevance to this thesis: 1) the Isakovo/Serovo consumed more meat from terrestrial fauna and less fish than the Kitoi and Glazkovo, 2) among the Isakovo/Serovo, dietary intake was not influenced by the gender or status of an individual, and 3) among the Kitoi and Glazkovo, dietary intake reflected the gender and status of an individual. The correlation of diet and social status can presently be conducted only in a cursory fashion as a thorough examination of this issue is substantially hindered by the lack of associated archaeological data; this thesis places its emphasis on identifying dietary differences that may be attributed to culture and gender.

The one alternative model of the Baikal Neolithic, presented by Goriunova & Vorob'eva (1986), postulated a general consistency in subsistence activity, irrespective of culture, throughout this entire period. Due to the its simplicity and its failure to incorporate variables such as gender and status, the validity of the Goriunova & Vorob'eva model should be adequately addressed by the testing of Hypothesis 1 above. In evaluating said hypotheses by means of isotopic and elemental analyses, this thesis may contribute to the foundation and impetus for a future reassessment of the subsistence strategies employed by the prehistoric inhabitants of the Baikal ecosystem.

1.5 Bone Chemistry and Paleodietary Studies

Beginning with a number of studies in the 1970's (Vogel & van der Merwe, 1977; van der Merwe & Vogel, 1978; Brown, 1974; Lambert *et al.*, 1979; Schoeninger, 1979), the isotopic and elemental composition of archaeological human bone has been analyzed for information concerning prehistoric diets. To date, stable isotope analysis has been conducted primarily on bone collagen, which comprises most of the 30% of dry bone that is organic. The ratio of the stable carbon (C) isotopes can be used to estimate effectively the dietary contribution of maize and marine resources. The ratio of the stable nitrogen (N) isotopes reflects the dietary importance of meat, legumes, and seafoods. The ratios of the stable isotopes of other elements such as hydrogen (H), oxygen (O), sulfur (S), and strontium (Sr) have demonstrated the potential to provide paleoenvironmental and paleodietary information but currently await wide application in archaeological studies (Schoeninger & Moore, 1992). Trace element analysis is conducted on the mineral portion of bone, which comprises approximately 70% of its dry weight. Levels of non-essential trace elements such as strontium and barium (Ba) may be examined individually as indicators of the amount of meat intake; strontium and barium together may provide an estimate of the intake of marine resources (Burton & Price, 1990). While a number of essential trace elements, including zinc (Zn), copper (Cu), manganese (Mn), and iron (Fe) are known to occur in different levels in meat, nuts, and plant foods (Whitmer *et al.*, 1989), their utility in paleodietary studies appears to be limited for a number of reasons to be discussed in the following chapter.

Early archaeological applications of stable isotope and trace element analysis met with apparently unequivocal success and concomitant enthusiasm (Vogel & van der Merwe, 1977; Brown, 1974; Schoeninger, 1979). In recent years, paleodietary reconstructions have become increasingly detailed, to the extent of quantifying the specific contribution of various resources to the diet of a population (Spielmann *et al.*, 1990; Schoeninger, 1989; Morton *et al.*, 1991). At the same time, researchers have begun to recognize a number of non-dietary factors that may affect the isotopic and, more dramatically, the elemental composition of prehistoric bone. As a result, some of the focus of this area of investigation has shifted from the reconstruction of prehistoric human diets to the documentation of the many taphonomic and environmental variables that may alter the chemical composition of bone. In Chapter Two, a brief overview of the use of trace element analysis in paleodietary research is presented, with an emphasis on those applications relevant to this study. A similar overview of stable isotope ratio analysis is presented in Chapter Three.

CHAPTER TWO -- TRACE ELEMENT ANALYSIS IN ARCHAEOLOGY

2.1 Trace Element Analysis -- An Overview

Concurrently with the earliest archaeological applications of stable isotope analysis, researchers began to recognize the potential contribution of trace element analysis to the reconstruction of prehistoric diets (Brown, 1974; Wessen *et al.*, 1977; Lambert *et al.*, 1979; Schoeninger, 1979). A number of elements -- including strontium, barium, zinc, copper, iron, manganese, vanadium (V), calcium (Ca), magnesium (Mg), and sodium (Na) -- are known to occur in different concentrations in plants, nuts, and meat, and have thus been proposed as possible dietary indicators (Buikstra *et al.*, 1989). In a recent study, Ezzo (1992*a*:221-222) delineated a number of criteria that an element must meet before its use in paleodietary reconstruction can be justified. The element should 1) concentrate and be measurable in bone, 2) reflect dietary intake and occur in concentrations that define a trophic-level or some other dietary separation, 3) not be an essential nutrient and thus subject to homeostatic regulation, but mimic the activity of an essential nutrient, and 4) become incorporated within, rather than simply onto the surface of, the hydroxyapatite crystal and thus remain relatively stable in the geochemical environment. Of the trace elements proposed as paleodietary indicators, only strontium and barium -- both of which, like calcium, belong to group IIA of the periodic table -- meet all of the above criteria (Ezzo, 1992*a*).

Researchers have expounded the advantages of multiple-element analysis in paleodietary research (e. g., Blakely & Beck, 1981; Whitmer *et al.*, 1989; Hatch & Geidel, 1985; Gilbert, 1985; Buikstra *et al.*, 1989). As most individual elements occur in high quantities in more than one type of food -- for example, magnesium concentrations are high in both plants and nuts (Klepinger, 1990) -- single-element studies often can not provide the level of resolution required in paleodietary studies. The combined use of several elements may provide clearer insight into the various components of prehistoric diet. Hatch & Geidel (1985:472) selectively analyzed five elements -- strontium, copper, zinc, manganese, and vanadium -- to distinguish between four types of diets -- vegetarian with nuts, vegetarian without nuts, meat-rich with nuts, and meat-rich without nuts. Their model was based on the documentation of high levels of strontium, manganese, and vanadium in vegetables; high levels of zinc and copper in meat; and high levels of zinc, manganese, and strontium in nuts. Despite their appeal, the acceptance of multi-elemental models remains contingent on the presence of a positive and consistent correlation between the dietary concentration of the specified elements and their level in the bone mineral of the consumer. Such a relationship has yet to be demonstrated for most essential elements. For example, in Klepinger's (1990) study, two groups of swine fed diets differing in magnesium content did not exhibit analogous differences in the elemental composition of their bones. The analysis of zinc, another essential element, has been conducted in a number of dietary studies with apparent success (Beck, 1985; Francalacci, 1989; Runia, 1987; Edward *et al.*, 1984), in other studies it has provided ambiguous results (White & Schwarcz, 1989; Byrne & Parris, 1987). Certain factors may affect the incorporation of ingested trace elements into bone mineral. Phytates present in cereals can combine with essential trace elements such as zinc, copper, and iron to form insoluble compounds, thus inhibiting their metabolic absorption (Lenihan, 1988; Byrne & Parris, 1987; Klepinger, 1984, 1992; Edward *et al.*, 1984). As a result, the levels of these elements cannot be used to infer dietary intake within different populations unless the extent and effect of phytate consumption can be assessed in each case. In addition, certain pairs of trace elements, such as copper and zinc, are antagonistic and inhibit the metabolic absorption of one another (Blakely & Beck, 1981). Excess dietary calcium has a similar antagonistic effect on many trace elements (Davis, 1972; Armelagos *et al.*, 1989). Finally, the levels of many of the trace elements potentially diagnostic of diet -- including copper, iron, and manganese -- are particularly susceptible to diagenetic alteration, often rendering them of little use in archaeological studies (Lambert *et al.*, 1984*b*; Vuorinen *et al.*, 1990; Byrne & Parris, 1987).

In this study, the levels of strontium, barium, and zinc are examined primarily for evidence of differential consumption of meat among the cultures of the Baikal Neolithic. Not considered to be essential trace elements, neither strontium nor barium is subject to homeostatic control. As an essential element, zinc does not meet one of the aforementioned criteria proposed by Ezzo (1992*a*). However, zinc analysis is employed here insofar as its utility has been demonstrated by a number of studies (Beck, 1985; Francalacci, 1989; Runia, 1987; Edward *et al.*, 1984). In addition, as barium is relatively untested in paleodietary studies, zinc may be used to construct a bivariate framework in which to evaluate the strontium data (e. g., Beck, 1985; Edward *et al.*, 1984). Table 2.1 presents a list of dietary components based on their levels of strontium, barium, and zinc, as derived from a number of different -- and occasionally contradictory -- sources (Monier-Williams, 1950; Whitmer *et al.*, 1989; Runia, 1988; Hambidge *et al.*, 1986; Burton & Price, 1990; Buikstra *et al.*, 1989). Due to the wide variation of elemental levels documented for most food groups (Hambidge *et al.*, 1986; Nielsen, 1986), this table should be regarded only as a simplified overview of the actual biological distribution of these trace elements.

	High levels in:	Low levels in:
Strontium	marine molluscs, vegetables, nuts, legumes, roots	meat, milk
Barium	vegetables	meat, seafood
Zinc	marine molluscs, nuts, meat, milk, cereals, legumes	marine fish, vegetables

Table 2.1: General distribution of Sr, Ba, and Zn in dietary components

2.1.1 Strontium

In the 1950's, a great deal of scientific attention was focused on strontium, particularly the isotope Sr-90 produced during atomic explosions (Comar *et al.*, 1957; Bohman *et al.*, 1962; Thurber *et al.*, 1958). As a result, the movement and distribution of strontium in the biosphere is well-documented compared to that of other trace elements.

Strontium is absorbed by plants from soil, generally with little change in concentration (Rheingold *et al.*, 1983). Soil concentrations of strontium vary geographically. Strontium chemically resembles calcium in that they are both alkaline earth metals and occur as divalent cations in solution. It can substitute for calcium in hydroxyapatite and other forms of calcium phosphate that comprise the mineral component of bone. Due to its larger ionic radius, strontium is subject to metabolic discrimination in favor of calcium -- a process known as the "biopurification of calcium " (Elias *et al.*, 1982) -- during digestion, absorption, and the formation of bone mineral by mammals, and is preferentially excreted by the kidneys. The *biopurification factor* (BPF) is calculated as:

$$\text{BPF} = (\text{nutrient Sr/Ca})/(\text{consumer Sr/Ca})$$

The BPF is the reciprocal of an earlier (and more commonly used) measure of the relative movement of strontium and calcium in biological systems. Comar *et al.* (1957:485) had proposed the use of the *strontium-calcium observed ratio* (OR), calculated as follows:

$$\text{OR}_{\text{sample-precursor}} = (\text{Sr/Ca of sample})/(\text{Sr/Ca of precursor})$$

In paleodietary studies, bone tissue and diet represent the "sample" and "precursor", respectively, of this equation. Both the BPF and OR are used to illustrate the extent to which strontium is metabolically discriminated against in favor of calcium. In general, it appears that human adults absorb 40-80% of ingested calcium and 20-40% of ingested strontium (Sillen & Kavanaugh, 1982). As over 99% of body strontium in vertebrates occurs in the mineral component of the skeleton (Schroeder *et al.*, 1972), animal flesh contains negligible concentrations of the element (Byrne & Parris, 1987). Due to these factors, the level of strontium in an organism varies inversely with its position in the food chain -- while both herbivores and carnivores discriminate metabolically against this element, meat in the diet of the latter group contains much smaller quantities of strontium. As a result, herbivores have lower Sr concentrations than their fodder, and predators have lower concentrations than their prey. This characteristic theoretically enables strontium levels to serve as an indicator of the dietary importance of meat among human populations.

While strontium concentrations are expected to distinguish between predator and prey within in a single ecosystem, the overall relationship between Sr concentration in the bones of an organism and its position on the food chain appears to be more complex than originally anticipated. Schoeninger (1989) presented Sr values for modern carnivores, wild herbivores, domesticated herbivores, and a human, all from northern Kenya. The value for the human individual fell between those of the carnivores and the domesticated herbivores, but in the middle of the range noted for wild herbivores. This observation suggests that the interpretation of human diet on the basis of strontium levels alone is a more complex task than theoretically anticipated. Sealy & Sillen (1988) have noted that, due to the variability in Sr/Ca ratios among different species within the same trophic level (e. g., herbivores), these values can be used only to distinguish specific predator and prey relationships within a food web, but not to compare the degree of meat consumption between human populations. These complexities in the interpretation of Sr levels may be attributed primarily to the omnivorous nature of human diet. Runia (1988) has noted that, while humans may consume significant amounts of low strontium meat, they may also consume items, such as cereals and roots, which have higher strontium levels than those plant foods that typically comprise herbivore diets.

The ability of strontium levels to distinguish between terrestrial and marine resources appears to vary geographically. For a sample of modern fauna from Greenland, Nelson *et al.* (1986) reported much higher strontium levels in seal than in terrestrial herbivores. Connor & Slaughter (1984) found similarly high Sr levels in polar bears compared with caribou in northwestern Alaska. However, in a study of human remains from 14 archaeological sites, Burton & Price (1991) found slightly lower mean levels among individuals with primarily marine diets than those with terrestial diets. Some researchers (Sillen & Kavanaugh, 1982; Harritt & Radosevich, 1992) have suggested that the consumption of marine vertebrates should not significantly enrich Sr concentrations in humans, simply due to the fact that most of the Sr in these animals is concentrated in bone, with only minute levels present in flesh. Sealy & Sillen (1988) observed little difference in Sr levels and Sr/Ca ratios between marine foods -- including molluscs -- and terrestrial plants from the southwestern Cape of South Africa. More research is required to assess the relationship between Sr levels in marine foods and that in local seawater.

While a number of studies have documented Sr levels in modern humans -- e. g., Thurber *et al.* (1958) presented a range of 101 to 344 ppm for a global sample; Byrne & Parris (1987) observed a mean of 91 ppm for a dozen Americans -- and animals (Schoeninger, 1985; Rheingold *et al.*, 1983; Sealy & Sillen, 1988), these values are subject to significant geographic variability and should be used only for gross comparative purposes.

2.1.2 Barium

Since the pioneering study by Toots & Voorhies (1965), strontium has been the element most commonly examined in paleodietary studies. More recently, researchers (Elias *et al.*, 1982; Lambert *et al.*, 1984*b*; Burton & Price, 1991; Ezzo, 1992*b*) have documented that barium, a Group IIA alkaline earth metal with a larger ionic radius than strontium, is subject to greater discrimination during the biopurification of calcium and thus should serve as a more sensitive indicator of trophic level. In the body, 93% of barium is deposited in the skeleton (Schroeder *et al.*, 1972) and, like strontium, it is virtually absent from flesh. A non-essential and non-toxic trace element, there is generally a paucity of data on the distribution of barium in organisms, including humans. One study (Schroeder *et al.*, 1972) presented a median value of 2 ppm of barium in human bone ash.

With few exceptions (Francalacci, 1989; Runia, 1987; Ezzo, 1992*a*), the examination of barium levels has yet to be widely used to examine the quantity of meat in prehistoric human diets. Contrary to the aforementioned expectations (Elias *et al.*, 1982; Burton & Price, 1991), in two paleodietary studies (Lambert *et al.*, 1984*c*; Ezzo, 1992*a*) that examine levels of both elements, barium did not appear more effective than strontium in illustrating temporal, sexual, and spatial variability in the diet of prehistoric populations. In another (Runia, 1987), comparison of barium levels offered little information of paleodietary value. An interpretive dilemma emerges when barium and strontium concentrations exhibit disparate patterns. Summarizing the results of a previous study (Lambert *et al.*, 1984*c*), Buikstra *et al.* (1989:162) noted that "barium, expected to follow the pattern for strontium, instead appeared to be less sensitive, not discriminating, for instance, between the sexes, at Gibson when contrasted with Ledders site." Given that barium is theoretically more effective at discriminating trophic levels, Buikstra *et al.*'s observation begs the question as to whether differences in strontium levels, *when unaccompanied by corresponding differences in barium levels*, truly reflect variability in the dietary intake of meat.

Another application for which barium analysis has proven effective is the distinction between terrestrial and marine (Burton & Price, 1990, 1991; Wessen *et al.*, 1977, 1978) and non-desert and desert resources (Burton & Price, 1991). Wessen *et al.* (1977) used barium concentrations to distinguish harpoons made from bones of terrestrial mammals from those made from bones of marine mammals. The high concentrations of sulfate in seawater and desert soils react with barium to form barite, an insoluble precipitate, thereby restricting the availability of barium for organic uptake in these environments (Burton & Price, 1991). As strontium remains relatively enriched in these mediums, the consumption of marine or desert resources should result in low Ba/Sr ratios.

2.1.3 Zinc

As a component of a number of vital metallo-enzymes, zinc plays an essential role in many metabolic processes in plants and animals. Deficiencies in zinc impair growth, recovery from wounds, reproductive functions, and proper skeletal development in humans (Underwood, 1975; Hambidge *et al.*, 1986). Zinc occurs in high concentrations in meat, seafoods, nuts, legumes, and cereals; however, the latter three groups also tend to be high in phytate, which inhibits zinc absorption by the body (Hambidge *et al.*, 1986). The role of zinc as an essential element subjects its concentration in tissue to homeostatic control; accordingly, some researchers have dismissed the usefulness of zinc as a paleodietary indicator (e. g., Ezzo, 1992*a*; Price *et al.*, 1992). When levels are more than adequate for metabolic requirements, excess zinc does appear to accumulate in bone mineral (Byrne & Parris, 1987); the relationship between the degree of this accumulation and the amount of zinc in diet has not been adequately assessed. In humans, approximately 28% of total body zinc resides in bone and teeth (Hambidge *et al.*, 1986).

Carnivores have been distinguished from herbivores on the basis of zinc levels in bone, with one study finding respective concentrations of 175-250 ppm and 90-150 ppm (Rheingold *et al.*, 1983). Zinc levels in modern human bones, as in other omnivores, tend to fall between those of carnivores and herbivores (Rheingold *et al.*, 1983) but exhibit a wide range from 100 to 250 ppm (Hambidge *et al.*, 1986). Byrne & Parris (1987) found no significant differences in zinc concentration between modern deer and human bone, but observed lower zinc levels in a sample of Middle Woodland human specimens than contemporary deer. This prehistoric difference was attributed to phytate consumption which inhibited zinc absorption among the humans. While the relationship between its levels in diet and bone requires further investigation, of all the essential trace elements, zinc currently appears to possess the most potential as a dietary indicator.

2.2 Sources of Ante-mortem Variation in Trace Element Concentrations

The applicability of trace element analysis in the reconstruction of prehistoric diets is contingent upon a comprehensive understanding of what Sandford (1992) has labelled the "biogenic-diagenetic continuum" -- the sum of the biological and post-depositional processes to which a bone is subject. Due to its particular relevance to archaeological research, the majority of recent trace element studies in archaeology has focused on the latter portion of this continuum and are discussed later in this chapter. The following sections review the sources of antemortem variation in the trace element concentrations in the bones of human individuals.

2.2.1 Biological variability in the content of bone mineral

The sources of antemortem variation in bone composition among individuals of the same population fall into two general categories: those that are a product of cultural practices (i. e., diet) and those that reflect biological variables such as sex, age, and individual metabolism (Whitmer *et al.*, 1989). A number of studies have demonstrated significant variation in the elemental content of bone mineral among different individuals within a population (Schoeninger, 1979; Price *et al.*, 1986), among the different bones of an individual (Bohman *et al.*, 1962; Tanaka *et al.*, 1981; Brätter *et al.*, 1977; Grupe, 1988), and even within a single bone (Tanaka *et al.*, 1981; Brätter *et al.*, 1977). Strontium levels in populations of mink (Schoeninger, 1979) and rats (Price *et al.*, 1986) raised on monotonous diets exhibited coefficients of variation on the order of 20%. Sampling a wild population of white-tailed deer from southern Wisconsin, Price *et al.* (1985*a*) observed a coefficient of variation of 34%. Price (1989:128) speculated that, for a sample of modern humans from a single locality, the CV would be between 20 and 25 percent. In adult individuals, strontium levels appear to increase slightly with age (Bohman *et al.*, 1962), probably due to the retention of the element in mineralized bone (Tanaka *et al.*, 1981). A negligible increase in barium values may also occur with age (Schroeder *et al.*, 1972). A gender difference in strontium values has been documented in the study of laboratory rats (Price *et al.*, 1986) and may be relevant to the interpretation of similar differences in prehistoric human populations (see below).

A number of studies have found that, among the skeletal elements of a single individual, the amount of variation in strontium levels falls within the range of measurement error (Schoeninger, 1981; Turekian & Kulp, 1956; Thurber *et al.*, 1958). Other studies have offered contradictory evidence, documenting significant variation in the levels of strontium, barium, zinc, and other elements among the different bones of a single individual, with the most noticeable difference occurring between cortical and trabecular bone (Tanaka *et al.*, 1981; Brätter *et al.*, 1977; Grupe, 1988). The maximum documented difference in Sr/Ca ratios between bones within a single, modern individual is on the order of 80%; within a single bone it is on the order of 25% (Tanaka *et al.*, 1981:606, 610).

In paleodietary studies, the same section of bone should be analyzed for the entire sample to minimize the variation in elemental levels observed between and within the bones of a single individual. In addition, archaeologists attempting to infer dietary differences between prehistoric populations based on trace element levels must demonstrate that observed differences in elemental concentrations fall significantly outside the range of expected variation between individuals on similar diets.

2.2.2 Geographic variability in strontium levels

As elemental concentrations in soil vary geographically, strontium levels in populations from different regions can not be compared directly. To circumvent this limitation, Price *et al.* (1985*a*) have suggested using strontium values of a local herbivore species as a baseline for comparing spatially distinct human populations. Within single drainage systems, strontium appears to occur at relatively constant levels (Alexander *et al.*, 1954, in Sillen & Kavanaugh, 1982; Templeton & Brown, 1964). Radosevich (1993), however, has noted that significant differences may occur in baseline strontium levels within limited areas and even between adjacent soil horizons. Geographic variability in zinc and barium concentrations has not been adequately documented.

2.3 Post-depositional Alteration of Trace Element Concentrations

Post-depositional events that affect trace element concentrations in buried bone include contamination, leaching, and diagenesis. While the term "diagenesis" technically refers to the occurrence of post-mortem chemical reconstitution of bone mineral (Lambert *et* *al.*, 1989), it has been used by most authors to refer to the sum of post-mortem effects, including contamination and leaching. In the following sections, it is used in this more general context.

When bone is interred, it becomes involved in interactions with the geochemical environment. The biogenic trace element concentrations are altered by several processes: 1) contamination as intrusive elements from the soil precipitate into the cracks and pores of bone, 2) contamination and leaching as ionic exchange occurs between soil and bone mineral, 3) the formation of new crystals on the original hydroxyapatite, and 4) the growth of existing crystals (Sandford, 1992). The rate and extent of diagenesis of bone mineral is affected by the pH, temperature, moisture, length of interment, chemical conditions, and level of microbial activity in the burial environment (Whitmer *et al.*, 1989; Von Endt & Ortner, 1984; Hanson & Buikstra, 1987; Pate & Hutton, 1988), as well as the size (Von Endt & Ortner, 1984; Lambert *et al.*, 1985*b*) and structure (Lambert *et al.*, 1982; Hancock *et al.*, 1987) of the bone material.

The ubiquitous impact of diagenesis may render most buried bone unsuitable for paleodietary studies using trace element analysis. Archaeologists have typically and optimistically underestimated the effects of diagenesis, adhering to six basic -- and at least partially erroneous -- assumptions, enumerated by Radosevich (1993:278-279) as: 1) the levels of certain elements -- including those possibly diagnostic of diet (i. e. Sr and Zn) -- are generally resistant to diagenesis in most burial environments; 2) if elemental concentrations are different between bone and surrounding soil, little diagenesis has occurred; 3) the extent of post-depositional alteration of bone is consistent within a single site or archaeological context; 4) due to the many different variables involved, elemental levels in modern bone cannot be compared with those of archaeological bone; 5) the large variation in trace element levels in interred bone reflects geographic differences; and 6) if the mineral portion of buried bone appears intact, it has retained its biogenic levels of Sr and, perhaps, Zn. Naturally, these assumptions are by no means universal among researchers, nor may they be entirely inappropriate when applied to specific situations. What becomes evident in the following review of research into diagenesis is that the propriety of any such assumption must be examined for each research problem confronted.

2.3.1 Recognizing diagenesis

Research into diagenetic processes has focused on the manifestation, rather than the mechanism, of post-depositional alteration. To assess the presence and extent of diagenetic effects, researchers have employed a number of methods including the comparison of elemental concentrations in trabecular and cortical bone, in human and faunal remains, in bone and adjacent soil, and across the thin section of a bone; the analysis of soil pH and moisture; the determination of the presence of yttrium and zirconium; the measurement of calcium/phosphorus (Ca/P) ratios and the ash and calcium content of bone specimens; and the application of multi-element studies (Price *et al.*, 1992). A sample of this research is summarized briefly below.

In a comparative study of ribs and femora, Lambert *et al.* (1982, 1984*b*) found cortical bone to be more resistant to post-depositional alteration than trabecular bone. Diagenetic processes in trabecular bone are facilitated by its porosity and relatively high surface area. Consistency in elemental concentrations between the trabecular and cortical bone of a buried individual may indicate the absence of diagenesis, but any such comparison must account for the biological difference in elemental levels between these two types of bone.

In their study of the effects of diagenesis on faunal remains from Greenland, Nelson *et al.* (1986) observed relative Sr levels in prehistoric specimens that differed significantly from those of their modern counterparts. Among the modern animals, marine species could be readily distinguished from terrestrial species on the basis of Sr concentration, but the Sr levels of the prehistoric specimens converged, indicating that diagenesis had removed this evidence of dietary separation between the two groups. The absence of expected trophic-level differences in elemental concentrations among prehistoric fauna from the same site, as well as the presence of gross differences between prehistoric and modern individuals of the same species, have been interpreted as being the result of significant diagenetic alteration (Sillen, 1981, 1986; Byrne & Parris, 1987).

Elemental analysis of the soil surrounding interred bone provides information on the exchange of ions between the two media and may be the most useful method of predicting diagenetic processes. Elemental homogeneity in the immediate burial environment may be interpreted to indicate either that no exchange has occurred or that the elemental levels of the two media have reached equilibrium. Higher and lower levels of elements in adjacent soil may be respectively interpreted to reflect leaching from and contamination of bone from soil (Whitmer *et al.* , 1989). In a study of Middle Woodland graves in Illinois, Lambert *et al.* (1984*a*) sampled soil at 5 cm intervals from buried femora. They found that Mn, Na, Sr, and Zn were homogeneously distributed around the skeleton. Aluminum (Al), Fe, and potassium (K) increased with distance from the interred, reflecting the movement of ions from adjacent soil into the bone. Ca and Mg decreased with distance from bone, indicating leaching from the skeleton. Their observations for some elements, including Na and Mn, contradicted those of their earlier studies (Lambert *et al.*, 1979, 1982). Their documentation of the leaching of Ca from bone led Lambert and his coworkers to suggest that the use of trace element/calcium ratios (e. g., Sr/Ca) is not appropriate for paleodietary studies (Buikstra *et al.*, 1989). This issue, and its implication for the study presented here, is discussed in Chapter Five.

A number of other studies (Pate & Hutton, 1988; Keeley *et al.*, 1977; Edward & Benfer, 1993; Radosevich, 1993) have documented the exchange of elements between bone and soil. The pattern of elemental exchange between bone and soil elements is generally expected to correlate directly with local soil composition. Alkaline earth elements such as Sr and Ba tend to leach from bone in acidic soils and accumulate in bone in arid and alkaline soils (Harritt & Radosevich, 1992). Bone preservation itself varies inversely with soil acidity (Gordon & Buikstra, 1981), so the examination of neutral and alkaline soils is most pertinent to this area of research. Pate & Hutton (1988) have suggested that only the concentration of soluble and exchangeable ions in soil, rather than its total elemental composition, is relevant to the study of diagenesis in buried bone. In a study of alkaline dune sand from an archaeological site in South Australia, they observed that silicon (Si), Al, and Fe were abundant in soil but relatively insoluble, while Ca, Mg, K, and Na represented the more soluble and exchangeable ions. In contrast, Edward & Benfer (1993) demonstrated the occurrence of ion exchange in the general absence of soil moisture and water movement in their study of diagenesis in Paloma, Peru.

Researchers (Lambert *et al.*, 1983) have used electron microprobe analysis to determine the distribution of elements across bone thin sections. High concentrations along the surfaces of the bone were interpreted as indicative of contamination from the soil. Lambert *et al.* (1983) observed such contamination of bone by Fe, K, Al, and Mn. Klepinger *et al.* (1986), using ICP analysis, examined transverse variation in elemental levels by analyzing endosteal and periosteal halves of long bones independently, and comparing the results with values for the entire cross-section. They discovered to their surprise that the values for the total cross-section often fell outside the range given by the endosteal and periosteal halves. Klepinger *et al.* (1986:330) attributed this somewhat suspect phenomenon to either the inhomogeneous microstructure of cortical bone or microvariation in the effects of diagenesis.

Katzenberg (1984) examined a sample of prehistoric human remains from southern Ontario for the presence of zirconium (Zr), yttrium (Y), and rubidium (Rb). These elements occur in extremely low levels in fresh bone; detectable levels indicate contamination from soil. Katzenberg (1984:84) observed positive correlations in the concentrations of these three elements. None of the elements exhibited a correlation with Sr, suggesting that levels of the latter element were not affected by soil conditions. Despite the apparent utility of the analysis of Zr, Y, and Rb, it has not been widely adopted in studies of diagenesis.

Presented in a number of studies (Price, 1989; Katzenberg, 1984; Sillen, 1989; Hancock *et al.*, 1989), calcium/phosphorus ratios, percentage calcium, and ash content in bone appear to provide somewhat ambiguous assessments of diagenetic effects. Ca/P ratios and calcium levels have been used to assess the extent of contamination by calcium carbonate or the leaching of calcium. However, using data from Katzenberg (1984), Price (1989) noted that phosphorus and calcium levels were positively correlated; therefore, Ca/P ratios may retain approximate biogenic values despite the effects of diagenesis. In Radosevich's (1993) study, several buried bone specimens that retained biogenic Ca/P ratios had also been subject to the most extensive contamination by diagenetic strontium. Under experimental conditions, Grupe & Piepenbrink (1988) observed that fungal activity may alter trace element concentrations without affecting Ca/P ratios. Percentage ash may provide an estimation of the preservation of the organic fraction of bone. While deviations from expected values for modern bone -- Ca/P$\approx$ 2, Ca$\approx$37%, ash$\approx$67% (Sillen, 1989; Price, 1989) -- are indicative of diagenetic effects, it has not been determined how variations in these values affect the levels of those trace elements diagnostic of diet. In addition, no researchers have speculated how far an observed value must vary from an expected value to render a specimen unacceptable for paleodietary interpretations.

A number of recent studies have examined a wide range of elements in order to determine the effects of diagenesis (e. g., Byrne & Parris, 1987; Price, 1989; Buikstra *et al.*, 1989; Edward & Benfer, 1993). The relationships among the multiple elements appear to be more complex and less predictable than previously anticipated. Soil constituents such as K, Mn, Fe, and Al tend to be positively correlated with one another, as they each contaminate bone, but should not correlate with dietary indicators such as Sr. Trace elements used for dietary interpretations should demonstrate positive (e.g., Sr and Ba) or negative (in some cases, Sr and Zn) correlations, reflecting their documented distribution in foods. While positive correlations for contaminants have been observed in a number of studies (e.g. Price, 1989; Buikstra *et al.*, 1989), the relationships between other elements have been more difficult to decipher. Expected correlations do not always occur, and some unexpected ones may emerge from any given analysis. For example, both Buikstra *et al.* (1989) and Price (1989) identified positive correlations between zinc and copper, despite their well-documented antagonism. It is apparent that the success of multiple-element studies will rely on more extensive documentation of the effects of diet and diagenesis of the levels of individual elements.

Finally, the coefficient of variation of strontium values has also been used as an indicator of diagenetic change (Blakely, 1989). As CVs theoretically decrease with time (and, by implication, extent of diagenesis) as bone approaches equilibrium with its burial environment, a low CV among contemporaneous individuals of a single species has been used to infer post-depositional alteration (Sillen, 1988). This decrease in CV through time has not been consistently observed at stratified sites (e. g., Wessen *et al.*, 1978), suggesting that the reliability of CVs as diagenetic indicators must be evaluated specifically for each study site.

2.3.2 Diagenetic effects on strontium, barium, and zinc levels

Initial studies of diagenetic effects on strontium levels produced equivocal results. A number of studies have suggested that strontium is relatively stable in the geochemical environment (Parker & Toots, 1980; Schoeninger, 1981; Schoeninger & Peebles, 1981; Edward *et al.*, 1984; Lambert *et al.*, 1982, 1983, 1984*b*, 1985*a*, 1989, 1990, 1991; Edward & Benfer, 1993). Other studies have demonstrated that strontium levels are subject to diagenetic alteration (Nelson *et al.*, 1986; Hancock *et al.*, 1987; Sillen, 1981, 1986; Byrne & Parris, 1987; Price *et al.*, 1992; Radosevich, 1993).

In a series of studies, Lambert *et al.* (1982, 1984*b*, 1984*c*, 1985*a*, 1985*b*, 1989, 1990, 1991) found Sr to be resistant to diagenetic processes. The overall consistency of their observations is not surprising, as they were all (with the partial exception of the 1990 study) based upon the analysis of material from the same three prehistoric sites -- Gibson, Ledders, and Helton -- in Illinois. For the same reason, a number of discrepant results produced by their series of studies may be cause for concern. Their assessment of the post-depositional reaction of the two other trace elements relevant to this study, Ba and Zn, has been less consistent and is discussed below.

As Ba is also known to replace calcium in hydroxyapatite, one would expect it to exhibit a geochemical stability similar to that of Sr (Pate *et al.*, 1989). A comparison of modern and archaeological desert fauna demonstrated that barium is more stable than strontium in this type of environment (Ezzo, 1992*b*). At a Hellenistic cemetery in Asine, Greece, Edward *et al.* (1984) observed Sr and Zn to be stable but that Ba appeared mobile, increasing in concentration with diagenesis. In another study, Lambert *et al.*, (1984*c*) used electron microprobe analysis to demonstrate significant diagenetic contamination of Ba levels by revealing disproportionate concentrations of the element along the outer surfaces of the bone. In a study of Roman skeletons, Ahlgren *et al.* (1981) noted that barium generally occurred in higher levels in ribs and long bone epiphyses than in long bone diaphyses, suggesting contamination of the trabecular bone. However, Ba values displayed much higher variance than Sr values, suggesting that they had been less seriously affected by diagenesis. Under laboratory conditions, Grupe & Piepenbrink (1988) documented significant enrichment of Ba in bone due to fungal activity. Recent studies (Lambert *et al.*, 1989, 1991; Buikstra *et al.*, 1989) have suggested that removal of the outer layer of cortex may counteract at least some of the diagenetic effect on barium levels.

A number of reports (Lambert *et al.*, 1983, 1984*b*, 1985*a*; Byrne & Parris, 1987; Edward & Benfer, 1993; Nelson & Sauer, 1984) appeared to confirm the geochemical stability of zinc in bone mineral. At the Black Earth site in Illinois, Nelson & Sauer (1984) found no correlation between zinc levels in soil and that in buried bone, and concluded that soil zinc did not permeate the bone. In their earlier studies, Lambert *et al.* (1983, 1984*b*, 1985*a*) used electron microprobe analysis of femoral cross-sections to demonstrate that zinc and strontium were homogeneously distributed between the periosteal and endosteal surfaces. More recently, Lambert *et al.* (1989, 1991) found considerable zinc contamination on the surface of buried bone. In one of these studies, the abrasive cleaning of visible surface contamination removed 40% of the zinc in the bone mineral (Lambert *et al.*, 1989).

Overall, the geochemical stability of bone appears directly related to the characteristics of its burial environment. The observations presented by the studies discussed above should be considered site-specific. As a result, diagenetic processes must be independently evaluated for each particular study site.

2.3.3 Recovering biogenic information from archaeological bone

While some researchers (Hancock *et al.*, 1987) have suggested that the extent and unpredictability of diagenetic processes render trace element analysis unsuitable for paleodietary studies, others have begun to experiment with methods to recover the original biogenic signal from archaeological bone.

Sillen (1986) applied series of 25 successive washes on powdered fossil bone using an acetic acid/sodium acetate buffer to separate diagenetic Sr. Diagenetic apatite that is deposited around biological bone mineral tends to differ in elemental composition and solubility. Under certain conditions, repeated washing in dilute acid will separate diagenetic from biological apatite. In this study, the solution from each washing, as well as the final residue, was analyzed. For a sample of Plio-Pleistocene fossil animals, it was the Sr/Ca ratio in the final series of washes (#20-25), rather than that of the final residue, that most closely approximated estimated biogenic values. The integrity of these recovered values has been questioned by Tuross *et al.* (1989), who did not have similar success in applying Sillen's technique. Pate *et al.* (1989) have also criticized Sillen's methods for possibly removing soluble ions from biogenic hydroxyapatite crystals. They suggested a number of refinements to Sillen's methodology, specifically the use of media of decreasing pH in the sequential washes to remove different types of carbonates.

Lambert *et al.* (1989) engaged in the physical removal of 1-3 mm of the periosteal and endosteal surface of bones with silicon carbide sandpaper. This procedure removed a considerable percentage of Zn, cadmium (Cd), K, Al, Fe, and Mn, with little effect on the overall representation of Na, Ca, Mg, Sr, and Ba. The evidence presented for movement of several elements (e. g., Ba) was ambiguous or contradictory, and the authors could not specify the degree to which they had reestablished the original biogenic elemental levels.

Lambert *et al.* (1990) compared four methods of specimen preparation for trace element analysis: A) brushing and rinsing with distilled water, B) physical removal of outer and inner bone surfaces, as described in Lambert *et al.* (1989), C) treatment of powdered specimen with acetic acid, the method used by Sullivan & Krueger (1981), and D) sequential washing of powdered specimen with an acetic acid/sodium acetate buffer, the method used by Sillen (1986). They concluded that complementary use of Methods B and D would result in the most effective recovery of antemortem elemental concentrations. Chemical cleaning alone can not remove insoluble surface contaminants, and likely reduces the biogenic levels of certain elements.

Despite the results of their 1990 study, Lambert *et al.* (1991) prepared prehistoric bone specimens by physical removal of bone surfaces, without additional acid washing. In this case, the removal of a 1 mm layer appeared sufficient to eliminate surface contamination. Sr was again evaluated as unaffected by diagenesis. The results for both Ba and Zn were ambiguous.

Price *et al.* (1992) compared three specimen preparation procedures: mechanical cleaning, soaking in acid, and washing with acid and a reducing agent. As expected, mechanical cleaning was deemed effective in reducing levels of surface contaminants but insufficient to counteract more pervasive diagenesis. Soaking with acetic acid removed calcium and carbonate contaminants and recovered the biogenic Ca/P ratio. Washing with acetic acid and hydroxylamine hydrochloride appeared to remove Ba-bearing oxides and recover biogenic barium levels more effectively than soaking in acetic acid alone. The positive evaluation of this last procedure was based on the expectation that biogenic Ba levels should correlate with those of strontium, an assumption that appears to require further testing.

In sum, a number of preparation procedures may reduce the extent of diagenetic alteration of trace element levels in bone, but conducting a proper evaluation of the efficacy of any particular method remains problematic. Even when an expected biogenic relationship among fauna (e. g., lower Sr levels in carnivores compared to herbivores) is reestablished, there is no assurance that the original elemental concentrations have been recovered (Tuross *et al.*, 1989). In addition, the differences in elemental levels in prehistoric human individuals should not reflect such dietary extremes and are likely to be more subtle. At the moment, the greatest contribution of the aforementioned studies of diagenesis has been to cast doubt on the findings of trace element studies that did not employ proper mechanical and chemical preparation techniques. Unfortunately, the latter comprise an overwhelming proportion of the studies conducted to date (e. g., Brown, 1974; Schoeninger, 1979, 1981; Schoeninger & Peebles, 1981; Katzenberg, 1984; Blakely & Beck, 1981; Connor & Slaughter, 1984; Edward *et al.*, 1984; Byrne & Parris, 1987; Blakely, 1989).

2.4 The Role of Trace Element Analysis in This Study

The previous sections have summarized the potential and limitations of trace element analysis in paleodietary studies. The issues of particular relevance to this study include the intercultural comparison of the dietary importance of aquatic resources and the intracultural correlation of meat intake with social variables such as gender and status. The possible contribution of trace element analysis to the examination of these issues is reviewed in the following sections.

2.4.1 Freshwater resources

The relationships between the strontium levels in fish and that of their diet and aquatic medium have not been clearly defined. Some studies in this area have focused on determining the OR of discrimination of aquatic strontium in fish tissues (e. g., Rosenthal *et al.*, 1970). Other researchers (Runia, 1987; Ophel & Judd, 1967) have suggested that the diet has a greater influence on strontium levels in fish than water content. Owing to this focus on observed ratios, listings of actual strontium levels are often and unfortunately omitted from published reports (e. g., Rosenthal *et al.*, 1970; Runia, 1987; Boroughs *et al.*, 1957). Strontium discrimination appears to occur to some extent in freshwater fish (Ophel & Judd, 1967). Rosenthal (1963) found that the highest levels of Sr in fish occurred in the spine, and the lowest in the flesh. In general, the strontium levels in freshwater fish are significantly lower than those of their marine counterparts, likely reflecting a similar (approximately five-fold) difference in concentration between freshwater and seawater (Rosenthal *et al.*, 1970).

Schoeninger & Peebles (1981) suspected that freshwater molluscs contributed to the high Sr levels found in the remains of Late Archaic hunter-gatherers buried in a shell mound in coastal Alabama; however, they did not analyze any mollusc samples in their study. Sealy & Sillen (1988) proposed that shellfish flesh did not significantly enrich Sr levels in human bone; instead, they suggested that the phenomenon observed by Schoeninger & Peebles (1981) resulted from diagenetic incorporation of Sr from the decomposition of shell in the burial mound. Strontium levels in marine molluscs exhibit significant geographic variability -- from a mean of 27 ppm for two species from the Irish Sea (Segar *et al.*, 1971) to a mean of 1430 ppm for one species from coastal Papua New Guinea (Kyle, 1986) -- but their correlation with the levels in local seawater has not been investigated in detail. As with fish, the shells of freshwater molluscs have much lower strontium levels than those of marine species. In both environments, mollusc shells contain higher strontium concentrations than fish (Rosenthal *et al.*, 1970). Elemental concentrations in the flesh of freshwater molluscs have not been adequately documented.

The range of aquatic species and environments examined for Sr levels has been quite limited, and no generalizations should be derived from the aforementioned studies. Zinc occurs at very low levels in sea-water (Monier-Williams, 1950) but its distribution in freshwater resources has not been documented. As discussed earlier in this chapter, barium levels and barium/strontium ratios can be used effectively to separate terrestrial and marine resources (Burton & Price, 1990, 1991; Wessen *et al.*, 1977, 1978). Burton & Price (1990) could not distinguish between freshwater fish and terrestrial animals on the basis of Ba/Sr ratios. The reliability of their results is suspect as, in that study, Burton & Price (1990) did not utilize the cleaning method (chemical cleaning with hydroxylamine hydrochloride -- see above) they later recommended (Price *et al.*, 1992) as most effective at recovering biogenic barium levels.

In sum, there is little information on the concentrations of strontium, zinc, and barium in aquatic food resources, and that available on strontium suggests that levels of this element are specific to aquatic environment. For the purpose of archaeological studies, the elemental levels of fish and molluscs must be examined for the relevant locality.

2.4.2 Differences due to gender

The use of strontium levels to examine dietary differences due to gender has been considered problematic for a number of reasons. Pregnancy and lactation affect calcium metabolism in females. During these times, the biopurification of calcium occurs during the passage of ions through placental tissue and mammary glands (Price *et al.*, 1986; Sillen & Kavanaugh, 1982). As a result, fetuses and young infants have relatively low Sr/Ca ratios, with the filtered strontium remaining in the system of the mother. In prehistoric populations, where it may be expected that women were pregnant or lactating during most of their adult lives, a significant gender difference in Sr/Ca ratios may appear even in the absence of an analogous difference in diet (Sillen & Kavanaugh, 1982; Klepinger, 1984). Price *et al.* (1986) discovered counter to their expectations that, of eleven archaeological sites in the midwestern U. S., strontium levels in females were significantly higher than those of males at only two sites. In another study, significant differences in strontium levels were documented between males and females at two prehistoric sites in Georgia (Blakely, 1989). At one site, strontium levels in reproductive-age females were significantly higher that those of post-menopausal females. Blakely (1989) attributed the high strontium levels in reproductive age females to both metabolic retention of strontium in maternal systems and greater consumption of strontium-rich foods, such as nuts. The differences in the diet of pregnant and lactating females may reflect dietary taboos restricting the consumption of meat (Blakely, 1989; Klepinger, 1984). It should be noted that the above studies did not incorporate any sophisticated cleaning procedures (e. g., Lambert *et al.*, 1989, 1990, 1991; Price *et al.*, 1992) and the documented gender differences may reflect diagenesis as well as diet.

Ezzo's study of Grasshopper Pueblo burials (1992*a*) -- in which the cleaning technique recommended by Price *et al.* (1992) was applied -- found that mean Sr/Ca and Ba/Ca ratios were significantly lower in males than in females for the early period (A. D. 1275-1325) but not for the late period (A. D. 1325-1400). The observed differences were attributed to diet; the possible effects of pregnancy and lactation were not discussed.

Another recent study (Radosevich, 1993) found extreme gender differences in Sr levels in prehistoric sample from Harappa, Pakistan, with female levels twice as high as those of the males. While all specimens were undoubtedly affected by diagenesis, Radosevich speculated that a calcium-poor diet among Harappan females resulted in greater ante-mortem adsorption of Sr and/or greater susceptibility to post-depositional alteration due to poor mineralization of bone. In this study, Radosevich employed physical cleaning techniques that Lambert *et al.* (1989, 1991) believed effective; however, no chemical cleaning was conducted during specimen preparation, as recommended by Price *et al.* (1992) and Lambert *et al.* (1990).

As a result of the aforementioned metabolic differences, relatively high strontium levels in prehistoric females may not necessarily reflect gender-related dietary differences. Conversely, lower or equivalent strontium levels in females may require explanation, but the effect of pregnancy and lactation on trace element concentrations in human females over an entire lifetime must first be adequately understood and quantified. It is of particular importance to paleodietary studies that the relationship between strontium concentrations and fertility be evaluated, as there appears to be substantial variation in fecundity (and periods of lactation) among hunter-gatherer females (Spielmann, 1988). Differences in reproductive patterns between prehistoric foragers and their agriculturalist contemporaries are likely even more significant, and should be accounted for before conducting comparisons between mean population levels of Sr.

The biopurification of calcium in maternal mammary glands and concomitant low level of strontium in human milk are reflected in correspondingly low levels in newborn human infants. Strontium is not discriminated against effectively by the gastro-intestinal tract of infants, and its levels increase dramatically during weaning, when strontium-rich solid foods begin to become incorporated into the diet (Sillen & Smith, 1984). As metabolic discrimination increases at about the age of three, strontium concentrations in infants begin to fall to adult levels (Sillen & Smith, 1984:240). This discrete pattern of increase and decrease in strontium levels in the early years of life is an important tool in paleodemographic studies of weaning patterns.

Little data concerning the effect of pregnancy and lactation on barium levels are available. Metabolic discrimination against barium should result in an increase analogous to that of strontium in maternal skeletons during pregnancy and lactation; this supposition remains to be tested. Zinc is known to be highly concentrated in milk, a characteristic which may result in reduced levels in lactating females (Jonxis, 1983, in Runia, 1987).

Zinc may also be metabolized differently in males and females. At the Dickson Mound site in Illinois, Gilbert (1985) found that zinc levels correlated positively with long bone growth in females but not males, and correlated negatively with pathologies in males but not in females. Based on this observation it was inferred that, in females, zinc was channeled to insure sufficient growth for reproductive activities, while in males, the main priority for zinc utilization was the metabolic maintenance against disease (Gilbert, 1985:354). It has not been determined if this difference in metabolic priorities reflects or results in any gender differences in zinc absorption and incorporation into bone.

2.4.3 Differences due to status

Researchers have also used trace element data to examine dietary differences due to status. By correlating status with burial wealth or location, some researchers (Schoeninger, 1979; Brown, 1974; Hatch & Geidel, 1985) have found strontium levels to vary inversely with status, suggesting that high status individuals in certain prehistoric societies consumed more meat. Studies of other prehistoric societies have not been as successful in documenting such dietary differences (Blakely & Beck, 1981; Brown & Blakely, 1985; White & Schwarcz, 1989). While both elements have been analyzed in several studies (Blakely & Beck, 1981; Brown & Blakely, 1985; Hatch & Geidel, 1985; White & Schwarcz, 1989), strontium levels are considered more diagnostic of status than zinc. Zinc occurs in high levels in both meat and nuts, which are not known to be a high status food. In addition, low levels of the element may result from phytate ingestion even in diets that include significant amounts of zinc-rich food (e. g., Edward *et al.*, 1984). Analysis of barium levels has been applied neither consistently nor successfully in the attempt to distinguish dietary differences due to status.

2.5 Summary

Despite almost two decades of archaeological applications, the utility of trace element data in the study of prehistoric diet remains the subject of controversy. This area of research has yet to achieve its theoretical diagnostic potential. Ironically, the abundance of trace element studies has not provided a comprehensive data base -- the inconsistency of the methodologies employed renders much of this data unsuitable for comparative purposes. These inconsistencies are clearly manifested in the wide range of skeletal parts, specimen preparation procedures, and trace elements represented in these studies. Standardization of these variables is essential to the success of future trace element studies.

The brief overview in this chapter has identified a wide range of non-dietary variables, including background environmental differences and diagenetic processes, that may affect the levels of trace elements in both modern and archaeological bone. Much of the research concerning the ante-mortem incorporation of trace elements into bone was conducted over twenty years ago and requires update. The variability in both ante- and post-mortem incorporation and loss of trace elements in bone mineral has precluded the formation of predictive models essential for the study of diet and diagenesis. Recent studies toward recognizing and counteracting post-mortem alteration of trace element concentrations (Lambert *et al.*, 1989, 1990, 1991; Price *et al.*, 1992) have suggested that, in certain situations, biogenic relationships between specific elements may be recovered from archaeological bone, and it is with this hope that the research presented here is conducted.

Trace element analysis is employed in this study to examine the effects of diagenesis and, providing that they are minimal or can be effectively countered, to compare the relative consumption of the meat of terrestrial fauna between the three cultures of the Baikal Neolithic. Levels of iron, magnesium, manganese, calcium, and phosphorus are measured as they reflect the presence and extent of post-depositional alteration and the integrity of bone mineral. If unaffected by diagenesis, strontium and barium levels are expected to be relatively low among individuals who consume large quantities of meat. The concentration of zinc should vary directly with meat intake (and inversely with strontium and barium levels) unless its absorption is inhibited by the presence of phytates or antagonistic elements. The ability of these trace elements to distinguish between the terrestrial and freshwater resources must be evaluated independently for each ecological situation and is addressed in this study by means of the analysis of a sample of terrestrial and aquatic fauna from the Lake Baikal region. A sample of cedar nuts was analyzed to determine whether high levels of any of these elements could be attributed to nut consumption. The elemental levels in males and females are compared for the Kitoi, the only one of the three cultures that includes individuals of both genders in sufficient quantity (n = 5) to warrant statistical testing. The possibility that any observed disparity in elemental levels between genders may be attributed to differences in diet and/or biological variables is examined.

CHAPTER THREE -- STABLE ISOTOPE ANALYSIS IN ARCHAEOLOGY

3.1 Stable Isotope Analysis -- An Overview

A number of recent articles review the history, theoretical basis, and archaeological applications of stable isotope analysis of the organic component of bone (DeNiro, 1987; Katzenberg, 1992; Schwarcz & Schoeninger, 1991; Schoeninger & Moore, 1992; Keegan, 1989; Price *et al.*, 1985*b*). Since its initial application in archaeological studies (Vogel & van der Merwe, 1977; van der Merwe & Vogel, 1978), isotopic analyses of prehistoric diets have focused almost exclusively on carbon and nitrogen. The relative concentration of these two elements in an animal's bone collagen is strictly regulated by metabolic processes, but the ratios of the stable isotopes of both elements have been demonstrated to reflect the isotopic composition of that animal's diet (Price *et al.*, 1985*a*). For these elements, the heavier stable isotopes, ^{13}C and ^{15}N, occur at much lower frequencies than their lighter counterparts (^{12}C and ^{14}N), representing only 1.1% and 0.36% of total carbon and nitrogen in nature, respectively. $^{13}C/^{12}C$ and $^{15}N/^{14}N$ ratios are typically expressed as δ (delta) values in parts per mil (‰) relative to the isotopic ratio in the accepted standard for each element. These values are calculated as follows:

$$\delta^{13}C(‰)=\{[(^{13}C/^{12}C)_{sample}]\div[(^{13}C/^{12}C)_{standard}] - 1\} \times 1000$$

$$\delta^{15}N(‰)=\{[(^{15}N/^{14}N)_{sample}]\div[(^{15}N/^{14}N)_{standard}] - 1\} \times 1000$$

For carbon, the standard is based on the CO_2 derived from the combustion of fossil belemnite from the PeeDee formation in South Carolina (PDB); for nitrogen, it is atmospheric N_2, also referred to as ambient inhalable reservoir (AIR) (Stothers & Bechtel, 1987; Schoeninger & Moore, 1992). Relative to these standards, most organisms have lower concentrations of ^{13}C (i. e., negative $\delta^{13}C$ values) and higher concentrations of ^{15}N.

Due to their greater atomic mass, ^{13}C and ^{15}N react at different rates from their lighter counterparts during chemical processes. The change in isotopic ratios between a reagent and a product that results from the discrimination against one isotope during a chemical reaction is termed "isotopic fractionation". Differences in δ values between an animal's tissues and its diet are typically attributed to fractionation during the incorporation of food into the system of the animal. The mechanisms of fractionation are not clearly understood and appear to vary among organisms. In addition, metabolic biases in the formation of certain tissues may affect isotopic ratios. The nitrogen in collagen is typically derived from consumed protein and does not reflect an animal's diet as a whole (Schoeninger, 1989). Similarly, each of the various dietary macronutrients -- proteins, lipids, and carbohydrates -- has different $\delta^{13}C$ values which may be disproportionately represented in animal tissue (Bumsted, 1985; Ambrose, 1993). Carbohydrates and proteins are similar in $\delta^{13}C$ values, but lipids are more negative by 7-8‰ (Chisholm, 1989; Vogel, 1978, but see Krueger & Sullivan, 1984, for other values). Dietary protein is believed to contribute the bulk of the carbon in collagen, which is 45% carbon (Krueger & Sullivan, 1984). Certain foods are particularly carbon-rich and will have a greater impact on $\delta^{13}C$ values per unit ingested than foods with lower carbon content (Bumsted, 1985). In addition, certain dietary components may be preferentially "routed" to specific tissues without contributing to the general carbon and nitrogen pool of the organism (Schwarcz, 1991:265).

While a range of fractionation values has been presented in the literature, it appears that the $\delta^{13}C$ values of the bone collagen and flesh of a large mammal are approximately 5-6‰ and 1‰, respectively, more positive than that of its diet. The $\delta^{15}N$ value of an animal's bone collagen is similar to that of its flesh (Sealy *et al.*, 1987) but is approximately 3‰ more positive than that of its diet (Schoeninger & DeNiro, 1984). The significance of these differences in δ values is discussed below.

The analysis of carbon and nitrogen stable isotope ratios has proved particularly effective in paleodietary studies for a number of reasons. Isotopic ratios observed within a single individual are consistent among the different skeletal elements, so that the analysis of any element should produce δ values representative of the entire individual (Chisholm, 1989; DeNiro & Schoeninger, 1983; Walker & DeNiro, 1986; Schwarcz, 1991; Katzenberg, 1992). Within populations of animals subsisting on monotonous or similar diets, variation of $\delta^{13}C$ and $\delta^{15}N$ values derived from collagen is less than 1‰, irrespective of the age or sex (Hobson & Schwarcz, 1986; DeNiro & Schoeninger, 1983). While the precise turnover rate of bone collagen in humans remains to be determined, it is generally accepted that complete turnover takes at least a decade and that δ values reflect long term dietary influence (Chisholm, 1989; Stenhouse & Baxter, 1979; Walker & DeNiro, 1986). As a result, the isotopic values of the individuals of a population subsisting on a generally similar diet will not be significantly affected by minor and temporary variations in food intake (Chisholm, 1989). This consistency of δ values within the bones of an individual and among members of a population sharing a similar diet facilitates the selection of prehistoric samples for archaeological studies.

Of equal importance, bone collagen is very chemically stable, and its carbon and nitrogen isotope ratios appear to be relatively resistant to alterations due to diagenesis, particularly in specimens recovered from temperate regions. Nelson *et al.* (1986) compared the ratio of strontium, carbon, and oxygen isotopes in the bone mineral and carbon and nitrogen isotopes in the bone collagen of prehistoric and modern animals from Greenland, with a focus on the distinction between marine and terrestrial feeders. The isotopic ratios in bone apatite was significantly distorted by diagenetic effects, but the $\delta^{13}C$ and $\delta^{15}N$ values in the collagen of the prehistoric specimens fell within the range of their modern counterparts, and the separation between marine and terrestrial feeders was preserved. When collagen breaks down or becomes contaminated, the extraneous products are usually soluble and can be readily removed before analysis (Chisholm, 1989).

In situations such as desert (van der Merwe, 1982) and tropical (Ambrose & Norr, 1992) environments where collagen degradation is rapid and diagenetic effects must be assessed, researchers have proposed criteria for recognizing specimens suitable for isotopic analysis. DeNiro (1985) found that prehistoric specimens with carbon/nitrogen ratios that fell within the range observed for modern animal bone (2.9 to 3.6) retained $\delta^{13}C$ and $\delta^{15}N$ values comparable to those of their modern counterparts. He proposed that prehistoric samples with a C/N ratio in this modern range retained their original stable isotope ratios. More recently, researchers have determined that neither the C/N ratio nor the concentration of collagen in bone samples (Schoeninger *et al.*, 1989; Schwarcz & Schoeninger, 1991; Ambrose & Norr, 1992) can adequately assess the extent of diagenetic alterations. Ambrose (1990) has suggested that the concentration of carbon and nitrogen in collagen are more accurate indicators of the effect of diagenesis on $\delta^{13}C$ and $\delta^{15}N$ values, and he (1993) noted that well-preserved prehistoric bone usually retains more than 1% collagen, which in turn must consist of more than 3% carbon and 1% nitrogen by weight. These aforementioned criteria are suggestive rather than definitive; that is, the failure to meet any one of them indicates some degradation or contamination of collagen but does not necessarily preclude the possibility that, with proper treatment, a sample of the original collagen may be recovered. The only way to unequivocally demonstrate the integrity of archaeological collagen is by analyzing its amino acid composition (e. g., Schoeninger *et al.*, 1989; Katzenberg, 1989).

3.1.1 Stable carbon isotopes

Stable carbon isotope ratios in prehistoric bone can be used to distinguish the dietary contributions of two groups of terrestrial plants and to recognize the relative importance of terrestrial and marine resources. In their intake of CO_2, terrestrial plants employ one of two photosynthetic pathways which is reflected in their $\delta^{13}C$ values. The Calvin photosynthetic pathway is employed by C_3 plants and produces initial compounds of three carbon atoms. C_4 plants, with their Kranz leaf anatomy, can process CO_2 more efficiently than C_3 plants (van der Merwe, 1982), following the Hatch-Slack photosynthetic pathway to produce a compound with four carbon atoms. A third group, known as CAM (Crassulacean acid metabolism) plants, can use either of the aforementioned pathways. C_4 plants have $\delta^{13}C$ values in the range of -16 to -9°/₀₀, while $\delta^{13}C$ values for C_3 plants range from -33 to -22°/₀₀ (DeNiro, 1987). The natural flora of temperate regions, such as North America and Europe (van der Merwe, 1982), consist almost exclusively of C_3 plants. C_4 plants are primarily indigenous to open, arid environments and include a number of significant cultigens such as maize, sorghum, and millet. There is evidence that the fractionation between diet and herbivore bone collagen is greater when the former consists of C_4 plants (6°/₀₀, compared to 5°/₀₀ for C_3 plant consumers) (van der Merwe, 1989).

The $\delta^{13}C$ values of CAM plants, which include succulents such as pineapple and cacti, vary according to the photosynthetic pathway each employs. While Farnsworth *et al.* (1985) have documented a situation in the Tehuacan Valley in which CAM plants may have comprised a significant prehistoric food source, this group of plants generally does not appear to have contributed to the diet of most prehistoric populations.

In addition to being able to separate C_3 and C_4 plants, $^{13}C/^{12}C$ ratios have also been effectively used to distinguish between terrestrial and marine resources. Because they obtain their carbon from a different reservoir -- dissolved carbonate rather than atmospheric CO_2 -- marine plants have $\delta^{13}C$ values that differ from those of terrestrial C_3 plants, being on average 7°/₀₀ more positive (Chisholm *et al.*, 1982). The range of $\delta^{13}C$ values in marine plants does overlap with those of both C_3 and C_4 terrestrial plants (DeNiro, 1987), but the mean values for each group appear distinct.

Stable carbon isotope ratios can not be used to determine the amount of meat in an animal's diet. As discussed above, the $^{13}C/^{12}C$ ratio of an animal's flesh is only on the order of 1°/₀₀ more positive than that of its diet (DeNiro & Epstein, 1978). Therefore, the $\delta^{13}C$ values of herbivores and carnivores should be approximately 1°/₀₀ more positive than the average values for the plants and animals they respectively consume. This small expected difference is typically undetectable, given the range of variation in $\delta^{13}C$ values within individuals, between individuals, and between prey species, as well as the limited precision of analytical instrumentation. Browsing herbivores have $\delta^{13}C$ values similar to those of the C_3 plants they consume, and the $\delta^{13}C$ values of grazing herbivores can be expected to reflect their diet of C_4 grasses. Similarly, the $\delta^{13}C$ values of carnivores can be expected to overlap with those of their prey (Schoeninger & DeNiro, 1984).

In sum, $\delta^{13}C$ values are low in the C_3 food web, high in the C_4 food web, with values for marine fish and mammals falling generally between these two terrestrial groups. Table 3.1 presents a general list of modern $\delta^{13}C$ ranges for potential food resources. Modern and prehistoric $\delta^{13}C$ values may not be directly comparable due to the lowering of atmospheric $\delta^{13}C$ by industrial pollution during the past two centuries (Sealy & van der Merwe, 1992).

	$\delta^{13}C$
C_3 plants	-36 to -22‰
CAM plants	-32 to -7‰
C_4 plants	-15 to -6‰
terrestrial herbivores (collagen)	-27 to -5‰
terrestrial carnivores (collagen)	-26 to -4‰
marine fish (collagen)	-14 to -7‰
marine mammals (collagen)	-15 to -7‰

Table 3.1: Modern $\delta^{13}C$ ranges for potential food resources (from Ambrose, 1993: Figure 2)

3.1.1.1 Stable carbon isotopes in bone apatite

Carbon occurs in the mineral portion of bone in the form of carbonate, which can replace the phosphate groups in hydroxyapatite (see Chapter Five for formula) and may make up as much as 5% of bone mineral (Krueger & Sullivan, 1984). Like collagen, the carbon isotope ratios of bone apatite have also demonstrated potential for providing dietary information (Lee-Thorp & van der Merwe, 1989; Sullivan & Krueger, 1981, 1983; Krueger & Sullivan, 1984). The fractionation in $\delta^{13}C$ between diet and apatite is much greater than that between diet and collagen. As most of the carbon in dietary protein is routed to bone collagen, the carbon in apatite is often derived from the other macronutrients -- carbohydrates and lipids. As a result, apatite $\delta^{13}C$ values can distinguish between herbivores and carnivores. Amongst the former, most of the ^{13}C incorporated into bone mineral originates from carbohydrates; amongst the latter, much of the ^{13}C in apatite may come from lipids, which are depleted in ^{13}C (Krueger & Sullivan, 1984). Initial studies by Schoeninger & DeNiro (1982, 1983, Nelson *et al.*, 1986, as noted above) demonstrated that the $\delta^{13}C$ values in apatite are subject to post-mortem change. Current preparation techniques are capable of distinguishing and removing the majority of contaminative carbonate, thus rendering bone mineral suitable for paleodietary analysis (Ambrose, 1993).

In this study, stable isotope ratio analysis of bone apatite was not conducted due to financial limitations.

3.1.2 Stable nitrogen isotopes

Stable nitrogen isotope ratios in prehistoric bone can be used to separate trophic levels and to distinguish the dietary contributions of two groups of terrestrial plants. A number of studies (Schoeninger & DeNiro, 1984; Schoeninger, 1985) have demonstrated that the $^{15}N/^{14}N$ ratio in both the flesh and collagen of carnivores is approximately 3‰ more positive than those of herbivores in the same ecosystem. The $^{15}N/^{14}N$ ratios in herbivore flesh and collagen are, in turn, 3‰ more positive than that of the plants they consume. Accordingly, $\delta^{15}N$ values can be used to separate herbivores and carnivores, distinguishing trophic levels within ecosystems.

Terrestrial plants can be separated into two groups -- legumes, which include beans, and non-legumes -- with distinct $\delta^{15}N$ values. Theoretically, legumes can fix both atmospheric and soil nitrogen and tend to have $\delta^{15}N$ values ranging from 1-5‰; non-legumes, which cannot fix atmospheric N_2, must utilize soil nitrogen and have $\delta^{15}N$ values between 6 and 10‰ (Ambrose, 1993). For similar reasons, nitrogen isotope ratios can also serve as an indicator of the consumption of marine resources. Unable to fix N_2, most marine plants obtain their nitrogen from dissolved nitrate and ammonium and have average $\delta^{15}N$ values of approximately 7‰ (DeNiro, 1987). Marine vertebrates typically have higher $\delta^{15}N$ values than their terrestrial counterparts (Schoeninger & DeNiro, 1984). High $\delta^{15}N$ values have also been attributed to freshwater fish; this issue is discussed later in this chapter.

Table 3.2 summarizes modern ranges of $\delta^{15}N$ values for potential food resources.

	$\delta^{15}N$
legumes	1 to 5‰
marine plants	-2 to 9‰
nonleguminous terrestrial plants	6 to 10‰
marine fish	10 to 16‰
terrestrial herbivores	9 to 16‰
terrestrial carnivores	13 to 22‰
marine mammals	13 to 23‰

Table 3.2: Modern $\delta^{15}N$ ranges for potential food resources
(from Ambrose, 1993: Figure 2)

3.2 Environmental Variability in Isotopic Ratios

Before attempting any paleodietary reconstruction based on isotopic data, it is necessary to recognize the variables which may affect isotopic composition of prehistoric bone. As noted above, a number of these variables affect the metabolic intake of C and N and are not thoroughly understood. In addition, many non-dietary environmental factors have been documented to affect stable isotope ratios. Variations in carbon isotope ratios occur within the oceanic reservoir and may reflect differences in temperature and corresponding increases in lipid abundance in marine organisms (Chisholm, 1989). Tieszen (1991) has documented variation in $\delta^{13}C$ values within terrestrial plant species that may be attributed to factors such as water stress, availability of light and nutrients, temperature, and altitude. In thickly forested areas, the "canopy effect" (van der Merwe, 1982) traps isotopically light carbon dioxide from the decomposition of floor litter, resulting in a gradient in leaf $\delta^{13}C$ values that increases with height. Other plants also exhibit significant internal variation in $\delta^{13}C$ values among their physical parts and their biochemical components (Ambrose, 1993). Research on African fauna has documented that climatic factors influence baseline $\delta^{15}N$ values and can result in a range of variation of over 10‰ within a species (Heaton *et al.*, 1986). This variation is most likely a reflection of physiological reactions to local water stress, specifically in the excretion of urea, which tends to be ^{15}N-depleted (Ambrose, 1991). Finally, the extent of isotopic fractionation between diet and collagen varies among species and environments (Ambrose, 1993).

3.3 Stable Isotope Analysis of Prehistoric Diet

The initial archaeological applications of stable isotope analysis were conducted to determine the importance of maize and to date its emergence in the diet of prehistoric North Americans (Vogel & van der Merwe, 1977; Bender *et al.*, 1981). This area of research, focusing on temporal variations in maize consumption, continues to be quite active (Blake *et al.*, 1992; Larsen *et al.*, 1992; Schwarcz *et al.*, 1985; Stothers & Bechtel, 1987; Spielmann *et al.*, 1990; Buikstra & Milner, 1991; White & Schwarcz, 1989; Farnsworth *et al.*, 1985; Ezzo, 1992*a*). Researchers have also used the C_3/C_4 dichotomy to identify human utilization of different groups of herbivores. In their study of Pecos Pueblo, New Mexico, Spielmann *et al.* (1990) attempted to determine the relative dietary contribution of traded bison meat compared to that of hunted mule deer. In this area, bison have high $\delta^{13}C$ values, likely from grazing on C_4 grasses, while mule deer exhibit $\delta^{13}C$ values consistent with a diet of C_3 plants. Research in East and South Africa has further documented this distinction in $\delta^{13}C$ values between grazers, which consume C_4 savanna grasses, and browsers, which consume leaves from trees and shrubs, in arid environments (Ambrose & DeNiro, 1986; Sillen, 1988).

The other widespread application of stable isotope analysis has been to determine the contribution of marine resources in the diet of coastal and inland populations (Chisholm *et al.*, 1982; Tauber, 1981; Walker & DeNiro, 1986; Schoeninger *et al.*, 1983; Larsen *et al.*, 1992; Lovell *et al.*, 1986*a*; Johansen *et al.*, 1986; Chisholm *et al.*, 1992; Minagawa & Akazawa, 1992). These applications examine variation in the importance of marine foods across time -- usually with respect to the advent of agriculture (Tauber, 1981; Larsen *et al.*, 1992) -- and space (Walker & DeNiro, 1986; Johansen *et al.*, 1986; Chisholm *et al.*, 1992; Minagawa & Akazawa, 1992; Lovell *et al.*, 1986*a*), with a recent focus on prehistoric migration patterns (Parkington, 1991; Sealy & van der Merwe, 1988; Clutton-Brock & Noe-Nygaard, 1990).

When both C_4 and marine resources are available to a population, $\delta^{13}C$ values alone can not distinguish between the contribution of terrestrial and marine foods in the diet; in such cases, nitrogen isotope ratios have provided the necessary discrimination. But aside from distinguishing terrestrial and marine resources (Schoeninger *et al.*, 1983), $\delta^{15}N$ values have not been as diagnostic of dietary patterns as had been originally anticipated (Schoeninger, 1989; Spielmann *et al.*, 1990). Despite the documentation of a 3‰ separation in $\delta^{15}N$ values between herbivores and their predators within certain ecosystems (Schoeninger & DeNiro, 1984), this distinction is often obscured in the complex marine and terrestrial environments of the lower latitudes (Ambrose, 1991). Even in ecological situations where the approximate 3‰ trophic-level separation in $\delta^{15}N$ values may be expected, stable nitrogen isotope ratios have not proven very effective in determining the importance of meat in the diet of specific prehistoric populations. The relative contribution of meat to the diets of contemporary prehistoric human populations within a limited geographical range likely did not vary enough to produce statistically significant differences in $\delta^{15}N$ values, particularly given the approximate 1‰ standard deviation in $^{15}N/^{14}N$ ratios observed among individuals raised on monotonous diets (DeNiro & Epstein, 1981). Schoeninger (1989) documented that in three distinct ecosystems, the $\delta^{15}N$ values in the human sample appeared to be inflated in light of their expected diets, overlapping or even surpassing those of local carnivores.

Finally, while $\delta^{15}N$ values are potentially useful in recognizing the consumption of beans and other legumes, either the prehistoric importance of this resource in areas such as North America has been overestimated (Schwarcz, 1991:272) or domesticated beans do not fix nitrogen and thus have $\delta^{15}N$ values similar to non-leguminous plants (Schoeninger & Moore, 1992); no population examined thus far has exhibited $\delta^{15}N$ values low enough to unequivocally demonstrate the dietary importance of legumes (Keegan, 1989).

3.4 The Role of Stable Isotope Analysis in This Study

The aforementioned studies may not all be directly relevant to the research presented in this thesis. There has been no documentation of the presence of C_4 plants or the distribution of legumes in the Lake Baikal region of Siberia, and the location of the lake effectively obviates any possibility of migration or trade that would have given local prehistoric inhabitants access to marine resources. As this study is specifically concerned with recognizing differential consumption of freshwater resources and with identifying differences in diet due to gender or status, previous contributions in these areas are reviewed below.

3.4.1 Freshwater resources

Aside from a handful of studies in North America, stable isotope analysis has not been used to address the importance of freshwater resources in prehistoric subsistence. The small number of studies that have provided isotopic values for freshwater fish seem to indicate that they exhibit $\delta^{13}C$ values similar to, but $\delta^{15}N$ values higher than, those of local terrestrial herbivores. Prehistoric fish bone and scale specimens from Wisconsin had $\delta^{13}C$ values ranging from -23.0‰ and -21.0‰, similar to those of prehistoric deer bone from the same region (-23.3‰ to -21.1‰) (Bender *et al.*, 1981). van der Merwe (1982) proposed, without specific documentation, that plants in soft water environments are similar in $\delta^{13}C$ values to C_3 plants, while those in hard waters (with an abundance of dissolved calcium and magnesium) are similar to C_4 plants.

The majority of isotopic data on freshwater fish has been collected in Canadian studies. Flesh samples of 4 freshwater fish from British Columbia produced $\delta^{13}C$ values of -28.8‰, less positive than those of terrestrial mammals (-25.5‰) and marine fish (-17.5‰) (Chisholm *et al.*, 1982). Katzenberg (1989) presented data for bone specimens from three freshwater fish recovered from the Kelly-Campbell site in southern Ontario. The respective $\delta^{13}C$ and $\delta^{15}N$ values were -20.8‰ and 8.8‰ for a pickerel, -23.1‰ and 3.6‰ for a sucker, and -17.8‰ and 9.9‰ for a walleye. For reference, bone from prehistoric white-tailed deer at the same site had average $\delta^{13}C$ values of -22.2‰ and $\delta^{15}N$ values of 5.5‰. With such a small sample of fish it is difficult to determine the significance of their δ values. The pickerel and walleye are both piscivorous, while the sucker consumes invertebrates and organic matter at the bottom of lakes. As noted by Katzenberg (1989), the trophic level of the piscivorous species varies with age (immature individuals eat invertebrates), so it appears that the $\delta^{15}N$ values must be interpreted in terms of the size of the individual from which the sample was taken for analysis. Based on these observations, she suggested that the high $\delta^{15}N$ values for human remains from the Kelly-Campbell site partially reflect the dietary contribution of freshwater fish.

Schoeninger *et al.* (1983; Schoeninger & DeNiro, 1984) questioned the ability of nitrogen isotope ratios to distinguish between freshwater and terrestrial resources. However, Schwarcz *et al.* (1985:203) stated that "typical herbivore flesh has a $\delta^{15}N$ value of about 8‰ while freshwater fish are about 16‰." Morton *et al.* (1991) adopted a $\delta^{15}N$ value of 10.4 ± 2.3‰ for freshwater fish, compared to a value 6.0 ± 2.5‰ for terrestrial herbivore flesh. Schwarcz (1991:268, Figure 3) concluded that freshwater fish have $\delta^{13}C$ values similar to those of terrestrial herbivores but $\delta^{15}N$ values more comparable to those of marine fish belonging to the lower trophic levels (e. g., herbivores and omnivores).

3.4.2 Differences due to gender and status

Few isotopic studies of dietary differences due to gender and status have been conducted on hunter-gatherer populations. In a study of Oxbow hunter-gatherers, Lovell *et al.* (1986*b*) did not detect differences in isotopic ratios due to age, sex, or status. Walker & DeNiro (1986) hypothesized that a possible source for the variation in stable isotope ratios observed for individuals from certain pre-agricultural sites on the California coast was a gender difference in subsistence activity and diet; however, data on the gender of the individuals represented in their sample were not sufficient to test this hypothesis. Chisholm *et al.* (1992) found significant gender differences in $\delta^{13}C$ values for a number of prehistoric populations in coastal Japan. At some Hokkaido sites, the mean values for males were more negative than those of the females, but at two sites in southwestern Japan, the reverse situation was observed. This contrast was interpreted to reflect differential access to food resources during gender-specific foraging activities. In the former case, men appeared to have hunted inland while women gathered molluscs and other seafoods; in the latter, men fished and hunted sea mammals while women gathered terrestrial foods. Sealy *et al.* (1992) documented gender differences in $\delta^{13}C$ values among Holocene foragers from the southwestern Cape of Africa. Males exhibited more positive $\delta^{13}C$ values than females, implying that the former consumed a larger proportion of marine foods. Incidentally, Sealy *et al.* (1992) also noted a rough positive correlation between dental attrition and $\delta^{13}C$ values, likely due to the presence of sand in seafood.

In a number of studies of prehistoric agricultural populations, differences in isotopic ratios have been interpreted to reflect status or gender. Bender *et al.* (1981) documented a wide range of $\delta^{13}C$ values among a small sample of maize agriculturalists at the Middle Mississippian sites at Azatlan ($n = 8$) and Cahokia ($n = 6$). Status was inferred by the observed burial ritual. At Azatlan, high status individuals exhibited more negative $\delta^{13}C$ values; at Cahokia, the opposite situation was observed. In the same study, bones representing three males and three females from a Late Woodland burial mound were analyzed. The males and females had average $\delta^{13}C$ values of -15.4°/₀₀ and -18.1°/₀₀, respectively, with no overlap between their ranges. The authors inferred a greater consumption of maize by the Woodland males.

From a Middle Horizon cemetery in the Viru valley, Peru, Ericson *et al.* (1989: Figure 4.8) found that, in a sample of eight individuals, the $\delta^{13}C$ and $\delta^{15}N$ values of the three females were clustered within the distribution of values for the five males. The authors hypothesized that these respective ranges may have reflected differential access to resources -- with the males having a more varied diet -- or simply individual food preference. At the Mayan site of Lamanai, White & Schwarcz (1989; Schwarcz, 1991) found that one of two individuals buried in elaborate tombs had lower $\delta^{13}C$ values and higher $\delta^{15}N$ values than the population mean, respectively indicating less consumption of maize in conjunction with a greater intake of marine foods -- a dietary pattern that the authors attributed to higher status. At Grasshopper Pueblo, Arizona, Ezzo (1992*a*) found that females had lower $\delta^{13}C$ values during the early period, indicating a greater intake of wild C_3 plants; during the late period, male and female diets could not be distinguished isotopically, implying a mutual reliance on maize.

3.5 Summary

In its short history, stable isotope analysis has made considerable and consistent contributions to the study of paleodiet. This avenue of investigation has proven ideal for archaeological research for a number of reasons. δ values do not vary significantly among the bones of an individual nor between individuals on similar diets; as a result, small samples may be considered representative of entire populations. δ values are fairly resistant to post-depositional alteration, and the occurrence of diagenetic change can be unequivocally identified through amino acid analysis. Due to its slow turnover, bone collagen carries a long-term record of individual diet. And, perhaps most importantly, isotopic ratios distinguish between groups of food resources that are specific to particular forms of prehistoric subsistence such as maize agriculture, hunting, and fishing.

A number of issues concerning the relationship between δ values in diet and in collagen remain to be clarified. The isotopic contribution to bone collagen of different dietary components such as lipids, proteins, and carbohydrates, must be assessed. In addition, the assumption of a simple linear relationship between diet and collagen δ values (e. g., Schoeninger, 1989; Ambrose, 1993) must be tested more thoroughly. Nevertheless, the current state of knowledge concerning isotopic ratios and diet provides a more than adequate foundation for studies, including the one presented here, whose goal is the comparison of dietary patterns between populations rather than the quantification of the contribution of specific food items to their diet.

In this study, it was not anticipated that carbon isotope ratios would reveal any differences between the three cultures. There is no evidence that any of these cultures practiced agriculture nor documentation that any plants indigenous to this area employ the C_4 photosynthetic pathway. $\delta^{13}C$ values have not been used to differentiate freshwater fish from terrestrial herbivores, and while they may distinguish between terrestrial and marine resources, the location of the sites involved effectively dismisses any possibility of a marine component in the diet of Baikal populations. On the other hand, nitrogen isotope ratios have the potential to identify differential consumption of fish. As discussed above, $\delta^{15}N$ values are expected to be significantly more positive for fish than for terrestrial herbivores. This distinction is particularly relevant to the testing of Okladnikov's (1964) hypothesis that the Kitoi and the Glazkovo relied heavily on fish. $\delta^{15}N$ values are also higher in flesh than in plants and could possibly be used to detect differences in meat consumption between cultures and genders. Among the specimens selected for stable isotope analysis in this study, the Kitoi and Isakovo/Serovo samples include individuals of both genders in sufficient quantity ($n \geq 5$) to permit a statistical evaluation of sex-related dietary variations.

CHAPTER FOUR -- LABORATORY AND ANALYTICAL METHODS

4.1 Sample Selection

As discussed in Chapter One, a number of issues concerning the subsistence activities and social organization of the Neolithic populations of the Lake Baikal area invite further investigation. This study employs trace element and stable isotope ratio analysis to compare the dietary patterns of the three Neolithic cultures. The human and faunal specimens examined in this study belong to a sample of approximately 300 bones obtained by Dr. Andrzej Weber from the archaeological collections at the Institute of Archaeology and Ethnography, Russian Academy of Sciences, Novosibirsk, and Irkutsk State University, Irkutsk, Siberia. The human sample was selected arbitrarily from excavated Neolithic and Bronze Age burials from the Lake Baikal region. The age, sex, and cultural affiliation of the interred individuals had been previously determined by local Russian physical anthropologists and archaeologists.

In order to minimize the possibility and extent of regional variations that may affect baseline isotopic and elemental levels, specimens originating from two sites of general proximity were chosen for study. Lokomotiv and Ust'-Ida are both located on the Angara River. Lokomotiv is located on a high promontory in Irkutsk, 55 kilometers downstream of Lake Baikal. Ust'-Ida lies at the confluction of the Ida and Angara Rivers, approximately 175 kilometers downstream of the lake (Figure 1.1). Due to rising river levels, Ust'-Ida now lies only two to three meters above the Ida River. The burials at Lokomotiv are all believed to represent the Kitoi culture, while those at Ust'-Ida have been classified by Russian archaeologists as either Isakovo/Serovo or Glazkovo, depending on the body position of the interred. At Ust'-Ida, the Glazkovo individuals were attributed to this culture due to their flexed arrangement, but no diagnostic copper or bronze artifacts were recovered from their graves (A. Weber, pers. comm.). At this site, the Isakovo/Serovo burials were interspersed among those of the Glazkovo. C-14 dates from nine burials place Lokomotiv at circa 5720-5300 BC (Mamonova & Sulerzhitskii, 1989; V.

I. Baziliiskii, pers. comm.). At Ust'-Ida, dates for eleven Isakovo and four Glazkovo burials have given respective ranges of 4020-3210 BC and 3170-2660 BC. Unfortunately, no information on associated grave goods was available for individuals at either site.

4.2 Trace Element Analysis

Twenty-three adult individuals were chosen for trace element analysis. The selection of specimens and the size of the sample were dictated by the limited availability of material, and it was not possible to have each culture and gender equally represented. The sample included specimens from five Kitoi females, five Kitoi males, four Isakovo/Serovo females, three Isakovo/Serovo males, four Glazkovo females, and two Glazkovo males. Because trace elements differ in concentration between and within the bones of a single individual, an effort was made to minimize such possible variation. Only fibula and fibula fragments were selected for this portion of the analysis. Approximately two grams of bone were cut from the midshaft of each fibula; in the case of fragmented pieces, the segment closest to the midshaft was removed. The comparative prehistoric faunal sample consisted of bones from two seals (*Phoca sibirica*), a roe deer (*Capreolus capreolus*), an elk *(Cervus elaphus*), and a dog (*Canis familiaris*). The canid specimen was recovered from the site of Obkhoi in the Upper Lena Valley, the remainder of the sample from Khuzir, a site on Ol'khon Island in Lake Baikal (Figure 1.1). A sample of modern cedar (*Thuja* sp.) nuts, an ethnographically documented resource of Siberian peoples, was also analyzed.

The specimens were prepared for analysis according to the experimental procedures described by Burton & Price (1990:549). After cutting, each specimen was weighed (W1). Approximately 1 mm of the discolored periosteal surface was removed with waterproof silicone carbide sandpaper mounted on a turntable grinder. The endosteal surface was exposed, moistened with deionized water, and scraped thoroughly with a scalpel. The specimens were weighed again (W2), placed in vials, and sonicated for 15 minutes in deionized water. The vials were drained, refilled with 1-N acetic acid, sonicated again for

15 minutes, drained, refilled with 1-N acetic acid, and left to soak overnight. The specimens were then rinsed with deionized water, placed in a drying oven at 70°C overnight, weighed (W3), transferred to porcelain crucibles, and ashed in a muffle furnace at approximately 700°C for eight hours. After cooling, the ashed specimens were weighed once again (W4) and then ground to a powder with an agate mortar and pestle. For each specimen, approximately 0.050 grams of ash (W5) was weighed into a test tube, and 0.5 milliliters of concentrated nitric acid was added. Each tube was placed for 90 minutes in an oil bath heated to 120°C, allowed to cool, then diluted with 19.5 milliliters of 5% nitric acid to a final volume of 20 milliliters. In the case of the cedar nuts, which did not dissolve entirely, filter paper was used to remove any residue from the final solution. The solutions were analyzed for barium, iron, magnesium, manganese, strontium, zinc, calcium, and phosphorus, using a Leco Plasmarry Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES) in the Department of Chemistry, University of Alberta. Analytical precision of the instrumentation is ± 2% under ideal conditions. The International Atomic Energy Agency animal bone (H-5) standard and two standards (B0126 and B5407), obtained from the Laboratory of Archaeological Chemistry at the University of Wisconsin, were analyzed for reference. Due to financial constraints, each specimen was run only once. Analytical error was estimated using values from at least five repeated runs (n = 5 to 7, depending on element) of the Spectral Services laboratory standards. The CV observed for each element is presented in Table 5.1.

The acceptance of the trace element data presented here for dietary interpretation is contingent on the validity of two assumptions: 1) that the baseline (e. g., soil and ground water) concentrations of the trace elements examined are consistent between the two sites under investigation, thus justifying direct comparisons between them, and 2) that, as a result of the careful selection and preparation of specimens, the manifestations of diagenesis and biogenic variation have been minimized and, therefore, trace element levels for each individual reflect his or her diet.

The first assumption can not be adequately assessed without knowledge of the baseline elemental levels for each site microenvironment. As discussed in Chapter Two, strontium levels are known to vary with local environmental conditions, such as lithology, soil composition, and climate (Skougstadt & Horr, 1960), although they appear to be consistent within a single river or lake drainage systems (Price *et al.*, 1985*a*; Templeton & Brown, 1964). No prehistoric fauna was available for analysis from these sites. However, given the proximity of Lokomotiv and Ust'-Ida, it seems probable that the foraging radiuses of the prehistoric groups interred at these two sites overlapped geographically. These peoples likely migrated during the year to exploit seasonally specific resources. There is evidence that Isakovo/Serovo populations obtained lithic raw materials from distant sources in the Angara valley (Michael, 1958:47, 51), but the method of procurement -- direct access or trade -- has not been determined. The probable range of movement of the Neolithic inhabitants of this region suggests that local variations in elemental levels should be manifested as only a minor variable affecting the bone chemistry of an individual during the course of his or her lifetime. In any event, future paleodietary research in this region should be preceded by chemical analyses of fauna and flora (prehistoric if possible) to establish elemental baselines for comparison (cf. Price *et al.*, 1985*a*).

Assessing the validity of the second assumption also requires additional data, most importantly from the elemental analysis of the soil from each burial. For the purposes of this study, it is expected that the preparation procedure removed at least some of the post-depositional contamination, as demonstrated by Lambert *et al.* (1989, 1990, 1991) and Price *et al.* (1992). The final data are examined for correlations between elements and anomalous levels of particular elements that may reflect diagenetic influence.

4.2.1 Inductively Coupled Plasma Atomic Emission Spectrometry

Atomic emission spectrometry (AES) is a branch of analytical spectrometry which determines atomic frequencies by examining optical spectra emitted during excitation of the substrate. Inductively coupled plasmas (ICP) are one of the excitation sources employed in AES to dissociate and mobilize atoms and ions. A succinct description of ICP-AES is provided by Hart & Adams (1983), and is summarized here. A sample, typically in liquid form (as in this study), is drawn through a nebulizer and injected into a stream of argon in a spray chamber, creating an aerosol mist. In the chamber, the plasma, an ionized gas, sustains a stable and intense (> 6000 K) flame. The heat from the flame renders the atoms in the spray temporarily unstable and, as their electrons return to lower energy states, excess energy is emitted as spectra of light. Each element emits light which, when passing through a diffraction grating, is dispersed according to its characteristic wavelength. The intensity of the light reflects the mass representation of the corresponding element in the aerosol spray. The emission intensity of each element is measured by a set of photomultipliers, one specific to each element, and forwarded to a computer for processing. The detection limits for the elements examined in this study are given in Table 4.1.

Element	Ba	Fe	Mg	Mn	Sr	Zn	Ca	P
Detection Limit (ppm)	80	80	40	20	20	40	4000	4000

Table 4.1: Detection limits for elements examined by ICP-AES

The primary drawback of ICP-AES is its sensitivity to spectral interferences (Barnes, 1991). In addition, the high Ca and P levels in bone may cause plasma fluctuations and distortion of analyte signals (Pate *et al.*, 1989; Lee, 1983). In this study, interference from calcium distorted readings for aluminum and elevated the normal detection limit for iron.

4.3 Stable Isotope Ratio Analysis

Thirty specimens of human bones representing twenty-nine adult individuals were selected for carbon and nitrogen stable isotope ratio analysis (SIRA). The sample consisted of five Kitoi females, six Kitoi males, five Isakovo/Serovo females, five Isakovo/Serovo males, five Glazkovo females, and three Glazkovo males. As δ values do not vary significantly between the bones of an individual, the specimens designated for analysis included a variety of skeletal elements. The sample submitted for stable isotope analysis was larger than that for trace element analysis due to this greater liberty in specimen selection but was similarly restricted by the paucity of available material. In the case of one Lokomotiv female, segments of two long bones -- a radius and a humerus -- were analyzed. Five faunal specimens, representing the same species as those examined in the trace element study, and a sample of cedar nuts were also analyzed. The canid specimen submitted for SIRA originated from the same bone selected for the trace element analysis; the other faunal remains were recovered from Khuzir and Tyshkine III, another site on Ol'khon Island (Figure 1.1).

The entire sample of thirty-six specimens was sent to Geochron Laboratories in Cambridge, Massachusetts, for processing according to the methodology described in Krueger (n. d.). These procedures are briefly summarized here. Each bone specimen is first washed and cleaned mechanically before being rinsed and soaked overnight in 1N acetic acid. The bone is rinsed by decantation, dried at 90°C, and crushed into small (< 1 mm) fragments for further cleaning in sequential washes of 1N acetic acid. The bone powder is again rinsed and dried. One gram of powder is demineralized under vacuum with 100 ml of 1N HCl for approximately one hour. The remaining collagen is washed by decantation to remove salts and acid residue, boiled with a few drops of dilute HCl, and passed through fiberglass filters to remove insoluble contaminants. The dissolved collagen is evaporated, transferred to a beaker, and dried at 70°C to anhydrous bone gelatin. Gelatin samples are combusted with copper oxide to produce CO_2 and N_2 for analysis, as well as

H_2O, SO_2, and copper sulfate. The gases are separated -- H_2O in a dry ice bath, CO_2 in liquid nitrogen, and N_2 by absorption onto charcoal. Actual measurements of C/N ratios and percent collagen, carbon, and nitrogen were not recorded, but visual estimations indicated that they were all well within acceptable ranges (as discussed in Chapter 3.1).

Stable isotope ratios for CO_2 and N_2 were determined on a Micromass 903 triple-collecting mass spectrometer. Gas molecules were magnetically separated according to their mass into two beams of ions, and the voltage of each beam was measured to obtain the ratio of stable isotopes. Analytical precision is better than ± 0.1‰.

4.4 Statistical Analysis

While parametric statistical tests -- most notably Student's *t*-test -- have been applied to examine both trace element and stable isotope data, their propriety in the former case has been questioned (Buikstra *et al.*, 1989) due to observations that trace element values do not necessarily exhibit normal distributions. In the statistical analysis presented in the following section, all distributions are tested for normality and homoscedasticity. However, as the small sample sizes involved in this study may not reveal the true nature of their distribution, differences in mean values between genders and cultures are examined using both a parametric (Student's *t*) and a less powerful, non-parametric (Mann-Whitney *U*) test, following in part the example of Francalacci & Borgognini Tarli (1988). In addition, both parametric (Pearson product-moment) and non-parametric (Spearman rank) correlation coefficients are presented. Gilbert (1985:355) cautioned against the stringent application of statistical rigor (e. g., the arbitrary selection of 0.01 or 0.05 levels of confidence) that may dismiss relationships that merit further examination. In the following section, differences significant at $p \leq 0.05$ are documented but, where warranted, other anticipated relationships are noted. All tests and correlations were run on SPSS/PC+.

CHAPTER FIVE -- RESULTS AND DISCUSSION

5.1 Differences Due to Culture

5.1.1 Trace element data

Table 5.1 presents the values for barium, magnesium, strontium, zinc, calcium, phosphorus, and ash content (W4/W3) for all human specimens.

Culture-Number	Sex	Ba	Fe	Mg	Mn	Sr	Zn	Ca	P	Ca/P	ash
GI-01	F	196	111	1873	*	303	139	41.6	18.0	2.31	67.8
GI-02	F	391	*	10301	144	1375	223	40.8	17.5	2.33	67.4
GI-05	M	156	*	5100	*	571	121	42.3	17.2	2.45	67.2
GI-07	M	217	*	2806	*	480	131	41.9	17.4	2.41	67.4
GI-08	F	301	*	2380	*	640	132	42.3	17.2	2.47	66.5
GI-09	F	185	96	8596	*	1003	180	40.3	17.3	2.32	67.0
IS-02	F	542	*	5166	*	620	131	43.1	17.7	2.44	70.9
IS-03	F	283	*	2422	*	686	132	42.2	17.2	2.45	68.1
IS-04	F	428	*	3327	97	1406	159	42.7	16.6	2.57	66.3
IS-05	F	387	*	2816	153	1165	138	41.3	16.8	2.47	67.3
IS-06	M	404	87	9423	*	639	179	39.9	18.3	2.18	69.9
IS-09	M	248	*	8163	*	1158	161	41.0	16.8	2.45	67.0
IS-10	M	275	*	5747	*	1212	160	41.0	17.3	2.37	67.2
Ki-04	F	295	852	1310	351	298	138	41.4	17.3	2.39	70.9
Ki-12	F	330	137	1807	*	282	125	41.5	17.7	2.34	66.9
Ki-13	F	236	113	1507	131	292	117	40.2	17.6	2.28	70.9
Ki-14	F	423	1154	1270	846	367	204	42.3	17.3	2.44	69.9
Ki-15	M	265	*	1384	*	245	128	42.8	17.6	2.44	68.9
Ki-16	M	346	1852	1380	391	272	288	41.0	17.1	2.40	70.9
Ki-17	M	229	784	1504	108	240	261	42.0	16.7	2.52	70.1
Ki-18	M	353	2268	1352	480	324	353	41.3	17.6	2.34	71.4
Ki-19	F	208	547	1194	507	407	212	41.0	17.3	2.37	75.2
Ki-20	M	215	173	1735	*	239	200	41.7	17.2	2.43	71.0
CV (%) for standard		12.4	4.5	1.5	5.3	7.0	6.2	1.4	1.8	n/a	n/a

Table 5.1: Trace element concentrations for human fibula specimens
(Ca, P, and ash in %, others in ppm; * detection limit)

Mean levels and standard deviations for barium, magnesium, strontium, zinc, calcium, phosphorus, and ash content are presented in Table 5.2. Similar values for iron and manganese are found and discussed in a later section. Correlation matrices are presented in the Appendix (Table 7.1).

	n	Ba	s. d.	Mg	s. d.	Sr	s. d.	Zn	s. d.
Glazkovo	**6**	**241**	**88**	**5176**	**3530**	**729**	**392**	**154**	**39**
Male	2	187	43	3953	1622	525	64	126	7
Female	4	268	97	5788	4290	830	462	168	42
Isakovo/Serovo	**7**	**367**	**105**	**5295**	**2700**	**984**	**325**	**151**	**18**
Male	3	309	83	7777	1868	1003	316	167	11
Female	4	410	107	3433	1213	969	379	140	13
Kitoi	**10**	**290**	**72**	**1444**	**198**	**297**	**56**	**203**	**79**
Male	5	282	65	1471	159	264	36	246	86
Female	5	298	85	1418	247	329	55	159	45

	n	Ca	s. d.	P	s. d.	ash	s. d.
Glazkovo	**6**	**41.5**	**0.8**	**17.5**	**0.3**	**67.2**	**0.5**
Male	2	42.1	0.3	17.3	0.1	67.3	0.2
Female	4	41.3	0.9	17.5	0.4	67.2	0.6
Isakovo/Serovo	**7**	**41.6**	**1.1**	**17.2**	**0.6**	**68.1**	**1.7**
Male	3	40.6	0.6	17.4	0.8	68.0	1.7
Female	4	42.3	0.8	17.1	0.5	68.2	2.0
Kitoi	**10**	**41.5**	**0.7**	**17.4**	**0.3**	**70.6**	**2.1**
Male	5	41.8	0.7	17.2	0.4	70.5	1.0
Female	5	41.3	0.7	17.5	0.2	70.8	3.0

Table 5.2: Element means and standard deviations (Ca, P, and ash in %; others in ppm)

The distributions of the trace element values for each culture were tested for normality both according to the formulae presented by Sokal & Rohlf (1981) and by using the Kolmogorov-Smirnov Goodness of Fit test -- for all trace elements, the null hypothesis of normality could not be rejected. Values for ash content did not pass the test for normality. The use of Student's *t*-test appeared justified for the analysis of the trace element data but not for ash values. Due to the small sample size involved, results of the Mann-Whitney *U* test are also presented for all variables. Table 5.3 lists the p values comparing the different cultures. The Isakovo/Serovo specimens have significantly higher levels of barium than their Glazkovo counterparts; for all other elements, there are no significant differences between the two cultures. Due to the general similarity in mean elemental levels and correlations between the Isakovo/Serovo and the Glazkovo specimens, they are considered as a single group -- the Ust'-Ida sample -- in the following discussion of trace elements except for those cases in which they behave in different manners (Ba and Zn). The levels of magnesium and strontium are statistically lower among the Kitoi (the Lokomotiv sample) than among the Ust'-Ida sample. Before these observations can be used to support an interpretation of dietary differences between the Kitoi and the later cultures, the possibility that they may simply reflect the burial conditions at their respective sites is examined below.

	test	Ki vs. IS	Ki vs. Gl	IS vs. Gl	Ust'-Ida vs. Lokomotiv
Ba	*t*	0.092	0.243	**0.041**	0.657
Ba	M-W *U*	0.097	0.159	**0.046**	0.804
Mg	*t*	**0.009**	**0.049**	0.946	**0.001**
Mg	M-W *U*	**0.001**	**0.001**	0.568	**0.000**
Sr	*t*	**0.001**	**0.043**	0.225	**0.000**
Sr	M-W *U*	**0.001**	**0.003**	0.153	**0.000**
Zn	*t*	0.077	0.189	0.870	0.085
Zn	M-W *U*	0.329	0.386	0.886	0.264
Ca	*t*	0.899	0.961	0.938	0.907
Ca	M-W *U*	0.845	0.745	0.886	0.951
P	*t*	0.585	0.566	0.433	0.899
P	M-W *U*	0.435	0.786	0.317	0.733
ash	*t*	*	*	*	*
ash	M-W *U*	**0.021**	**0.003**	0.514	**0.001**

Table 5.3: Elemental p-values for two-tailed *t*-tests and Mann-Whitney *U*-test; $p \leq 0.05$ in **bold**;
* distribution not normal

5.1.1.1 Calcium, phosphorus, calcium/phosphorus ratio, and ash content

Bone consists of approximately 70% inorganic mineral, the exact composition of which continues to be debated. It has been described as a non-stoichiometric analog of hydroxyapatite (Sillen, 1989), which has the formula $Ca_{10}(PO_4)_6(OH)_2$ and comprises approximately 60% of bone mineral (Posner, 1967). Calcium and phosphorus contribute 40.3% and 18.4%, respectively, of the mass of hydroxyapatite (Hancock *et al.*, 1987). According to this formula, the expected Ca/P mass ratio in hydroxyapatite is 2.16, but due to the presence of immature calcium phosphate phases -- which comprise about 40% of bone mineral and have lower Ca/P ratios (Posner, 1967; Pate & Hutton, 1988; Pate *et al.*, 1989) -- the true overall ratio should be closer to 2 (Sillen, 1989). In a sample of modern human femoral heads, Hancock *et al.* (1987) documented a mean Ca/P value of 2.17 for the cancellous portion, but a higher mean of 2.32 for the cortical component. During the course of the study presented here, a sample of nine modern deer bone prepared with the same technique as the prehistoric sample produced a mean Ca/P ratio of 2.36 ± 0.08. These larger than expected values may be due to the inflation of Ca values by ICP instrumentation (Lee, 1983; see Chapter 6.3), but the single run of the IAEA H-5 bone standard produced acceptable values for both Ca and P (Appendix: Table 7.2).

The Ca/P ratios of the prehistoric human specimens average 2.40 ± 0.09, with a range of 2.18 to 2.57. Calcium levels for the entire sample of specimens are fairly constant, with a mean of 41.53 ± 0.84% and a range of 39.86 to 43.10%. Phosphorus levels are similarly consistent, with a mean of 17.32 ± 0.42% and a range of 16.62 to 18.28%. Calcium and phosphorus levels and Ca/P ratios for all specimens fall within the range observed for both fired modern bone and other prehistoric samples (Hancock *et al.*, 1989; Price, 1989), suggesting a lack of significant post-depositional alteration of Ca and P concentrations. It should be noted that the occurrence of biological Ca and P levels in buried bone does not necessarily reflect similar integrity in trace element levels (Radosevich, 1993).

While ash content does not vary within each culture or site, it is higher among the Lokomotiv sample than that from Ust'-Ida. This slight but significant difference may have resulted either from lower organic preservation or more extensive post-depositional mineralization of the Lokomotiv specimens, both of which may be expected due to their greater length of interment. A positive correlation occurs between ash content and phosphorus at Ust'-Ida, but as no significant difference in P levels is observed between the two sites, the implication of this correlation on the preservational status of the respective samples is not immediately apparent.

5.1.1.2 Trace element/calcium ratios

In certain burial environments, researchers (Lambert *et al.*, 1982; Pate & Brown, 1985) have documented diagenetic depletion of calcium without a concomitant decrease in strontium, calling into question the propriety of using Sr/Ca ratios as an interpretive measure in paleodietary studies. In contrast, Byrne & Parris (1987) observed that Sr/Ca ratios and strontium levels were highly correlated and provided virtually identical statistical results in their paleodietary study of a Middle Woodland population. In this study, Zn, Ba, and Sr levels are all highly correlated with their respective ratios with Ca (Pearson's $r > 0.99$, $n = 24$, $p < 0.001$). For the remainder of this thesis, all analysis and discussion of these elements will refer to their concentration in parts per million.

5.1.1.3 Iron and manganese

Iron and manganese, along with aluminum, are considered to be primary soil contaminants of buried bone (Lambert *et al.*, 1991). Aluminum levels were not measured in this study due to spectral interference caused by high calcium concentrations. The majority of the Ust'-Ida sample have iron and manganese levels below detection limit, rendering statistical comparison with the Lokomotiv specimens inappropriate for these elements. For the same reason, correlation analysis could not be conducted for the former sample.

Manganese occurs at very low levels in modern bone. Tipton & Shafer (1964, in Armelagos *et al.*, 1989) give a range of 2-10 ppm for Mn in modern rib, a level below detection limit for the ICP-AES used in this study. The low levels of manganese among the Ust'-Ida sample indicate either that little contamination from soil occurred or that any such contamination was successfully removed during preparation procedures.

Tipton & Shafer (1964, in Armelagos *et al.*, 1989) give a mean of 400 ± 300 ppm for Fe in modern rib. The low levels of iron among the Ust'-Ida sample suggest that some leaching of this element may have occurred.

	n	**Fe**	s. d.	n	**Mn**	s. d.
Kitoi	**9**	**876**	**767**	**7**	**402**	**251**
Male	4	1269	961	3	327	194
Female	5	561	452	4	459	301

Table 5.4: Means and standard deviations for Fe and Mn (in ppm)

Table 5.4 presents mean levels and standard deviations for Fe and Mn for the Lokomotiv specimens; only individuals with levels above detection limit were included in the calculation of these values. The high levels of Fe in most of this sample (compared to the Ust'-Ida individuals) were likely due to the use of red ochre, which is predominately a ferric oxide (Fe_2O_3) (Goffer, 1980), to cover the deceased. The variable quantity of Mn among the Lokomotiv sample suggests that some soil contamination did occur at this site. The effect of such possible contamination on the concentration of those elements indicative of diet (Ba, Sr, and Zn) is discussed below.

5.1.1.4 Magnesium and strontium

An essential element, the distribution of magnesium in foods is similar to that of strontium -- high levels in nuts, plants, and seafoods, low levels in meat (Whitmer *et al.*, 1989). Despite more optimistic assessments by other researchers (e.g. Lambert *et al.*, 1991), Klepinger's (1990) experimental study effectively discredited the use of magnesium levels as dietary indicators. In her study, two groups of pigs whose diets differed in magnesium content by 180% exhibited no significant difference in bone magnesium levels. While known to be inhibited by phytates (White & Schwarcz, 1989), the absorption of magnesium by the body is generally a poorly understood process (Schwartz, 1988). Hancock *et al.* (1989) observed a mean Mg level of 3800 ± 400 ppm for a sample of fired cortical bone from seven modern human femora, Tipton & Shafer (1964, in Armelagos *et al.*, 1989) a value of 4600 ± 1000 ppm for modern rib, but the documented range of Mg levels in bone is extremely large (Armelagos *et al.*, 1989: Table 9.1).

Like calcium, strontium, and barium, magnesium belongs to group IIA of the periodic table and, of these elements, has the lowest atomic mass and smallest ionic radius. Magnesium can replace Ca in hydroxyapatite, but less pervasively and readily than Sr (Lambert *et al.*, 1985*b*). Its behavior during diagenesis has not been as predictable as might be expected given its chemical properties (Pate *et al.*, 1989). Byrne & Parris (1987) documented clear depletion of Mg in archaeological bone. Parker & Toots (1980) recognized that while bone tends to lose Mg during diagenesis, this element may be subsequently reintroduced into pore spaces. Lambert *et al.* (1991) found little contamination by Mg, but acknowledged the possibility of loss of this element through leaching. Grupe & Piepenbrink (1989) noted that fungal activity was a consistent cause of the depletion of Mg in bone. Benfer & Edward (1993) found contradictory evidence of magnesium movement between soil and bone at Paloma. Magnesium levels were higher in excavated bone specimens than in modern samples. In conjunction with the high levels of soil magnesium on site, this observation appeared to indicate Mg contamination of bone. At the same time, Mg levels in buried ribs were significantly lower than those of buried tibiae, suggesting that the element had leached from the former.

In this study, much higher levels of Mg occur among the Ust'-Ida sample than among the Lokomotiv sample (Table 5.2). While the Mg levels of several Ust'-Ida specimens appear inflated (> 8000 ppm), it is unfeasible on the basis of this element alone to assess the nature of post-depositional chemical alteration. The distribution of strontium is examined to provide greater insight into this issue.

Like magnesium, strontium occurs at much lower levels among the Lokomotiv specimens and the mean level for this sample more closely resembles modern values than do those of the Ust'-Ida sample. The striking difference in Sr and Mg levels between the samples from the two sites -- too large to be simply attributed to dietary factors -- undoubtedly reflect local burial conditions. Radosevich (1993) implied that when Sr levels over 1000 ppm -- as documented in almost half of the Ust'-Ida specimens -- are observed in prehistoric human samples, diagenetic contamination can be inferred. Such high Sr levels usually occur when the burial environment is arid and alkaline or located near seawater (Radosevich 1993:313). Once again, the evaluation of diagenetic processes in this study is hindered by lack of soil data. The location of the two sites may provide insight as to the diagenetic processes to which their burials were subjected. Ust'-Ida, situated on the low bank of a river, was likely subject to a bombardment of soluble ions, while Lokomotiv, on its high promontory, was primarily affected by soil contaminants. Mg and Sr are positively correlated in the Glazkovo sample (though not in the Isakovo/Serovo sample) from Ust'-Ida, but negatively among the Lokomotiv specimens (see Appendix: Table 7.1), suggesting that the high levels among the former resulted from the same mechanism, e.g., groundwater. Among the Ust'-Ida sample, Sr is negatively correlated with P, while Mg is negatively correlated with Ca. Sr also exhibits some correlation with ash content. The meaning of these correlations is unclear, but they may suggest that Sr and Mg levels are inversely related to the integrity of the hydroxyapatite. At Lokomotiv, Sr is positively correlated with Mn, indicating the probability of Sr contamination from soil.

While substantial Mg and Sr contamination of the Ust'-Ida specimens appears to have occurred, it remains to be determined whether this post-depositional alteration has completely obscured any possibility of comparing dietary patterns between the two sites. In their laboratory experiment, Lambert *et al.* (1985*b*) immersed bone in solutions concentrated in individual elements. While the increase of Zn and Sr was dramatic (1950% and 1170% for whole bone, respectively), magnesium levels rose by only 65%. In contrast, the difference in mean Mg levels between the Ust'-Ida and Lokomotiv specimens is over 300%, suggesting that groundwater contamination was not the sole factor responsible for the variation in elemental concentrations observed between the two sites. This difference may be attributed to the leaching of Mg from the Lokomotiv individuals, a speculation supported by the fact that the mean Mg level for this sample is much lower than that observed for modern human bone. It does not appear necessary to attribute any difference in Mg and Sr levels to dietary factors.

5.1.1.5 Zinc

There are no significant differences in zinc levels between the three cultures. The difference between the Isakovo/Serovo and Kitoi approaches significance when the *t*-test is applied ($p = 0.077$) but not when the Mann-Whitney *U* test is used (Table 5.3); no similar contrast is observed between the Glazkovo and the Kitoi. In the Glazkovo sample, zinc exhibits positive correlations with Sr; in the Isakovo/Serovo sample, it is positively correlated with both Sr and Mg. As no analogous correlations are evident in the Lokomotiv sample, it appears that Zn was affected by the same diagenetic processes that caused the high levels of Sr and Mg at Ust'-Ida. At Lokomotiv Zn levels are positively correlated with those of Fe but not with those of Mn, providing an ambiguous assessment of possible Zn contamination from soil. Diagenetic processes at the two sites affected zinc on a much smaller scale that the aforementioned elements as they did not result in any significant differences in zinc levels between the respective samples. Zinc values for all three cultures fall into ranges observed for modern samples (e. g., Armelagos *et al.*, 1989; Hambidge *et al.*, 1986).

5.1.1.6 Barium

Barium, like Fe, Al, and Mn, occurs both in clay and in oxides that may intrude into buried bone. In situations where Ba levels do not correlate with those of the other known contaminants, they have been used as paleodietary indicators (Ezzo, 1992*b*). As noted above, correlations between Ba, Fe, and Mn could not be determined for the Ust'-Ida sample. In the Lokomotiv sample, Ba shows a significant correlation with Mn using the *t*-test and correlations with Fe at $p < 0.10$ using both tests. As a result, Ba appears to be a contaminant at Lokomotiv. While differences in Ba levels among all three cultures approach significance, the only one significant at $p \leq 0.05$ occurs somewhat unexpectedly between the two cultures at Ust'-Ida. The mean Ba level for the Isakovo/Serovo is significantly higher than that of the Glazkovo. Being from the same site, the difference in Ba levels between the two samples can not be attributed to burial environment. It is possible that the length of interment of the older Isakovo/Serovo sample subjected it to greater contamination from soil barium.

As noted above, the specimens examined in this study were cleaned using 1 N acetic acid rather than the acetic acid/hydroxylamine hydrochloride mixture recently demonstrated by Price *et al*. (1992) to be most effective at removing contaminative barium oxides. It is not likely that biogenic barium levels were recovered by the preparation procedures employed in this study, a speculation supported by the evidence of diagenesis noted above.

5.1.1.7 Faunal sample

Trace element analysis of the five faunal specimens did not elucidate the situation observed among the human sample (Table 5.5). The two seal and two cervid specimens could not be distinguished on the basis of barium and strontium levels. While it was not possible to predict the relationship between seal and cervids due to the lack of information concerning the distribution of elements in the aquatic Baikal ecosystem, it was expected that they would cluster in respective groups. As all four specimens originated from Khuzir, it may be assumed that the observed anomalies were not the result of differences in burial environment and background elemental composition. Due to the extremely small sample size, differential diagenetic effects on a single specimen (or the failure to remove them during preparation) may have distorted any distinction in trace element composition among the faunal reference. Only for zinc do the faunal specimens fall into their expected groups. The two seal have higher zinc levels than the dog, which in turn has higher levels than the two cervids. The dog specimen was recovered from Obkhoi, so it may not be appropriate to compare its elemental levels with those of the Khuzir fauna.

	Ba	Fe	Mg	Mn	Sr	Zn	Ca	P	Ca/P	ash
Canis familiaris	1120	76	1989	*	1068	177	40.6	17.3	2.35	67.2
Phoca sibirica	1008	*	3127	*	1528	199	40.0	16.8	2.39	69.0
Phoca sibirica	695	297	1890	*	810	328	42.5	19.0	2.24	72.1
Capreolus capreolus	1287	*	2391	*	1136	100	39.8	16.0	2.48	74.4
Cervus elaphus	527	52	1727	*	578	167	40.4	16.4	2.46	70.9
Thuja Nuts	152	2355	80303	5725	13	2886	0.9	18.9	n/a	2.5

Table 5.5: Trace element concentrations for faunal specimens and nuts
(Ca, P, and ash in %, others in ppm; * detection limit)

The sample of modern cedar nuts exhibited extremely high levels of Fe, Mg, Mn, and Zn, and low levels of Ba, Sr, and Ca, but their original concentrations of these elements may have been altered by filtration. It is possible that the relatively high level of Zn in the Kitoi sample is attributable to nut consumption. Unfortunately, the other elements that occur in high quantities in the nut sample -- Fe, Mg, and Mn -- are not considered dietary indicators and their levels can not be used to confirm that nut consumption caused the elevation in Zn levels.

5.1.2 Stable isotope data

The collagen of the specimens submitted for analysis was determined at Geochron Laboratories to be of excellent integrity for isotopic analysis. As a result, site-specific diagenetic effects do not appear to be an issue here, and for the purposes of the following discussion, samples are referred to by culture rather than by site. Table 5.6 lists $\delta^{13}C$ and

$\delta^{15}N$ values for human specimens. The mean $\delta^{13}C$ and $\delta^{15}N$ values and their standard deviations for each culture are presented in Table 5.7.

Culture-Specimen Number	Sex	Skeletal Element	$\delta^{13}C$	$\delta^{15}N$
Glazkovo-01	female	fibula	-17.4	11.6
Glazkovo-02	female	fibula	-18.0	11.7
Glazkovo-03	female	femur	-18.2	10.4
Glazkovo-04	female	humerus	-17.9	11.4
Glazkovo-05	male	fibula	-17.4	12.8
Glazkovo-06	male	ulna	-18.4	12.2
Glazkovo-07	male	fibula	-17.2	11.3
[Glazkovo?]	[female?]*	[fibula?]	-21.1 -21.1	4.2 3.9
Isakovo/Serovo-01	female	clavicle	-18.0	11.1
Isakovo/Serovo-02	female	fibula	-18.1	10.3
Isakovo/Serovo-03	female	fibula	-16.4	13.0
Isakovo/Serovo-04	female	fibula	-18.6	11.8
Isakovo/Serovo-05	female	fibula	-17.6	10.9
Isakovo/Serovo-06	male	fibula	-17.5	9.8
Isakovo/Serovo-07	male	humerus	-17.0	12.4
Isakovo/Serovo-08	male	ulna	-17.3	12.9
Isakovo/Serovo-09	male	fibula	-18.5	11.6
Isakovo/Serovo-10	male	fibula	-18.1	12.1
Kitoi-01	female	clavicle	-15.9	12.2
Kitoi-02	female	humerus	-15.4	13.6
Kitoi-03	female	ulna	-15.0	13.8
Kitoi-04	female	fibula	-15.2	9.4
Kitoi-05	female	humerus radius	-16.0 -16.5	13.0 12.4
Kitoi-06	male	clavicle	-14.9	12.8
Kitoi-07	male	humerus	-15.5	11.5
Kitoi-08	male	ulna	-15.2	13.5
Kitoi-09	male	ulna	-15.0	14.4
Kitoi-10	male	ulna	-14.9	13.1
Kitoi-11	male	radius	-15.9	13.3

Table 5.6: δ values for human specimens (in ‰)
* possible herbivore misidentified as human

Because of its outlying values for both $\delta^{13}C$ (-21.1, -21.1) and $\delta^{15}N$ (4.2, 3.9), the fibula representing one Glazkovo specimen was analyzed twice, with no significant difference in result. This specimen may was likely an animal bone misidentified as human, a speculation subsequently confirmed by Drs. Nancy Lovell and Owen Beattie. Its δ values indicate its origin as herbivore. As a result, its values have been omitted from subsequent calculations and statistical tests. Two different skeletal elements -- a radius and a humerus -- were analyzed for Kitoi-05, and their δ values fell within the ≈ 1‰ expected range of intraskeletal variation. As with the trace element data, the null hypothesis of normality for the distributions of δ values within each culture could not be rejected.

	n	$\delta^{13}C$	s. d.	$\delta^{15}N$	s. d.
Glazkovo	**7**	**-17.79**	**0.46**	**11.63**	**0.75**
Male	3	-17.67	0.64	12.10	0.76
Female	4	-17.88	0.34	11.28	0.60
Isakovo/Serovo	**10**	**-17.71**	**0.69**	**11.59**	**1.07**
Male	5	-17.68	0.61	11.76	1.19
Female	5	-17.74	0.83	11.42	1.03
Kitoi	**11**	**-15.38**	**0.46**	**12.75**	**1.37**
Male	6	-15.23	0.40	13.10	0.95
Female	5	-15.55	0.52	12.32	1.76

Table 5.7: δ value means and standard deviations (‰)

	test	Ki vs. Gl	Ki vs. IS	IS vs. Gl
$\delta^{13}C$	*t*	**0.001**	**0.001**	0.803
$\delta^{13}C$	M-W *U*	**0.001**	**0.001**	0.961
$\delta^{15}N$	*t*	0.064	**0.044**	0.936
$\delta^{15}N$	M-W *U*	**0.026**	**0.024**	0.961

Table 5.8: Isotope p-values (two-tailed *t*-tests and Mann-Whitney *U*-tests)
$p \leq 0.05$ in **bold**

Table 5.8 lists the results of two-tailed *t*-tests and Mann-Whitney *U*-tests comparing the mean δ values for each culture. There are no significant differences in isotopic ratios between the two cultural groups from Ust'-Ida -- the Glazkovo and Isakovo/Serovo. According to both parametric and non-parametric tests, the mean $\delta^{13}C$ value for the Kitoi is significantly higher than those of the other two cultural groups, and their ranges do not overlap. The *t*-tests identified a significant difference in mean $\delta^{15}N$ values between the Kitoi and the Isakovo/Serovo, with a similar difference (but not statistically significant at $p \leq 0.05$) between the Kitoi and the Glazkovo. The Mann-Whitney *U*-tests found the mean $\delta^{15}N$ value for the Kitoi to be significantly greater than those of both the Glazkovo and Isakovo/Serovo. These cultural differences in δ values are discussed below with reference to the results obtained from the faunal sample.

For the entire data set, $\delta^{13}C$ values and $\delta^{15}N$ values are highly and positively correlated (Pearson's $r = 0.5172$, $n = 28$, $p = 0.005$). When examined individually, no significant correlations were observed within each culture, but this absence may be an effect of small sample size. Similar positive correlations between $\delta^{13}C$ and $\delta^{15}N$ values have been observed in coastal populations that subsist on a combination of C_3 terrestrial resources (low $\delta^{13}C$ and $\delta^{15}N$ values) and marine animals (high $\delta^{13}C$ and $\delta^{15}N$ values), such as the inhabitants of Rota Island in the southwest Pacific (Ambrose, 1993). A negative correlation between δ values can be observed among early agricultural populations, such as those of the Woodland of Northeastern America, in which consumption of maize (high $\delta^{13}C$ and low $\delta^{15}N$) and meat of C_3 herbivores (low $\delta^{13}C$ and high $\delta^{15}N$) are expected to have been inversely proportional to one another.

Correlations between δ values and elemental concentrations are presented in Table 7.1 of the Appendix for the Isakovo/Serovo sample, the only one that included a sufficient number of specimens analyzed for both isotopic ratios and trace element levels. No significant correlations between the isotopic and elemental data are observed. As δ values are presented as interval scale data -- that is, with an arbitrary zero point (Ambrose, 1993) -- it may be necessary to rescale them before they can be appropriately compared with elemental values (Buikstra *et al.*, 1989).

5.1.2.1 Faunal sample

δ values obtained for the faunal specimens and nuts are presented in Table 5.9.

Site	Species	Skeletal Element	$\delta^{13}C$	$\delta^{15}N$
Obhkoi	*Canis familiaris*	humerus	-18.8	8.8
Tyshkine III	*Phoca sibirica*	radius	-21.4	13.1
Tyshkine III	*Phoca sibirica*	radius	-21.5	12.8
Khuzhir	*Capreolus capreolus*	radius	-19.2	6.6
Khuzhir	*Cervus elaphus*	long bone	-19.5	5.1
modern	*Thuja* sp.	nuts	-22.7	1.3

Table 5.9: δ values for faunal specimens and nuts (in °/₀₀)

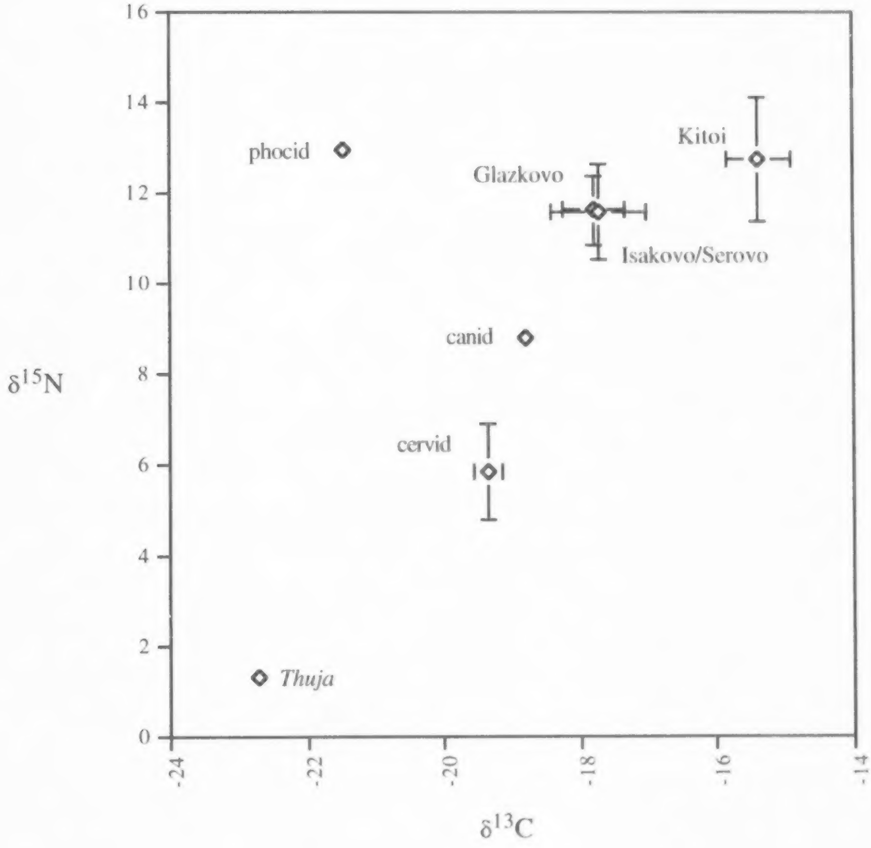
$\delta^{13}C$ values for the fauna exhibited a narrow range, from -18.8 to -21.5, but distinguished between the cervids, phocids, and canid. The seals exhibit low values typical of C_3 feeders; the less negative values for the cervids and the dog approach those of mixed C_3/C_4 feeders. The $\delta^{13}C$ values for the fauna are lower than those for the human individuals, with no overlap in ranges.

$\delta^{15}N$ values clearly distinguish between the cervids, phocids, and canid. The two seal specimens produced high $\delta^{15}N$ values (13.1 and 12.8°/₀₀). Assuming a 3°/₀₀ trophic level fractionation, the $\delta^{15}N$ values of the Baikal fish that comprise the diet of the seal should average approximately 10°/₀₀. The nitrogen isotope ratios for the cervids (6.6 and 5.1) fall in the range expected for herbivores. For the dog, the $\delta^{15}N$ value indicates that it consumed some meat or fish. Its δ values are noticeably distinct from the mean values for all three Neolithic cultures, suggesting that if it was a domestic individual, it consumed less meat or fish than the human population with which it was associated.

The results of the cedar nut analysis must be interpreted with caution. While the human and faunal data represent collagen values, the cedar nut sample comprises an actual dietary item. In addition, as the nuts represent a modern sample, differences between current and prehistoric $\delta^{13}C$ values must be taken into account. The burning of fossil fuels in the industrial age has lowered $\delta^{13}C$ values by about 2°/₀₀ (Sealy & van der Merwe, 1992), so it may be justified to assume that prehistoric cedar nuts had $\delta^{13}C$ values of approximately -20.7‰, a relatively high value for a C_3 plant food. No similar temporal difference is expected for $\delta^{15}N$ values. Assuming a respective 6‰ and 3‰ diet/collagen fractionation for $\delta^{13}C$ and $\delta^{15}N$, the collagen of a prehistoric human feeding exclusively on cedar nuts would approximate -14.7‰ and 4.3‰.

A graph of the δ values for the human groups, fauna, and cedar nuts is presented in Figure 5.1.

Figure 5.1: $\delta^{13}C$ vs. $\delta^{15}N$ for cultures, fauna, and nuts
(error bar represents ± 1 s. d.)



The human groups have $\delta^{15}N$ values similar to those of the seals -- indicating a reliance on aquatic resources -- but their $\delta^{13}C$ values are higher than those observed for any fauna. The faunal data indicate that the small difference in $\delta^{15}N$ values between the Kitoi and the two later cultures may have resulted from the greater consumption of aquatic resources (fish or seal) by the former. The significance of the larger difference in $\delta^{13}C$ values requires further investigation. The $\delta^{13}C$ values for the cervids are less negative than those of the seals. This observation, in conjunction with the high ratios observed for the nuts, may indicate that some of the terrestrial C_3 flora of the Baikal region have slightly higher $\delta^{13}C$ values than contemporary flora from other regions. The possibility that an unidentified C_4 resource contributed to the high stable carbon isotope ratios of both the cervid and human samples, especially those observed for the Kitoi, must also be examined.

5.2 Differences Due to Gender and Status

Table 5.10 presents the result of statistical analysis of gender differences in elemental levels and isotopic ratios for each of the three cultures. The Kitoi sample is large enough to permit a statistically justified examination of gender differences (n = 5 for both males and females) based on both elemental and isotopic data. Statistical comparisons are also appropriate in the case of the Isakovo/Serovo isotopic data (n = 5 for both genders). All other p values are presented as reference for future studies incorporating larger samples and are not discussed here in detail.

Assuming consistent diagenetic effects across the site, intrasite comparisons of elemental levels may be justified pending further examination of the burial environment at Lokomotiv. Among the Kitoi at this site, the mean of the male strontium levels is significantly lower than that of the females. The mean zinc value for the males is also noticeably higher than that of the females, although this difference is not significant at a 0.05 confidence level. Only slight differences occur between the mean values of the remaining elements. While the results for strontium and zinc may be interpreted as reflecting greater meat or nut consumption by males, other possible explanations exist. Radosevich (1993) observed a similar difference in Sr levels -- despite significant Sr contamination -- between males and females at Harappa. He proposed that higher Sr levels among the Harrapan females may have resulted from a calcium-deficient diet or metabolic differences due to pregnancy and lactation (as discussed in Chapter 2.4.2). The latter explanation may be more relevant to the Kitoi sample as it accounts for the differences in zinc concentration as well -- the high zinc level in milk may result in the observed reduction of the levels of this element among lactating females (Jonxis, 1983, in Runia, 1987).

	test	Ki -- M vs. F	IS -- M vs. F	GI -- M vs. F
Ba	*t*	0.735	0.235*	0.340*
Ba	M-W *U*	0.917	0.157*	0.355*
Fe	*t*	0.184**	n/a	n/a
Fe	M-W *U*	0.221**	n/a	n/a
Mg	*t*	0.695	**0.013***	0.607*
Mg	M-W *U*	0.465	**0.034***	1.000*
Mn	*t*	0.540**	n/a	n/a
Mn	M-W *U*	0.480**	n/a	n/a
Sr	*t*	0.057	0.905*	0.430*
Sr	M-W *U*	**0.047**	1.000*	0.355*
Zn	*t*	0.081	**0.036***	0.253*
Zn	M-W *U*	0.117	**0.034***	0.064*
Ca	*t*	0.323	**0.024***	0.279*
Ca	M-W *U*	0.465	**0.032***	0.355*
P	*t*	0.273	0.462*	0.535*
P	M-W *U*	0.251	0.480*	0.643*
ash	*t*	0.778	1.000*	0.391*
ash	M-W *U*	0.823	1.000*	0.480*
δ^{13}C	*t*	0.279	0.900	0.598*
δ^{13}C	M-W *U*	0.231	0.675	0.593*
δ^{15}N	*t*	0.386	0.643	0.165*
δ^{15}N	M-W *U*	0.584	0.602	0.289*

Table 5.10: Intracultural gender comparisons -- p-values for two-tailed *t*-tests and Mann-Whitney *U*-test (* n < 5 for each gender, **detection limit calculated as 0)
$p \leq 0.05$ in **bold**

No significant differences in stable isotope ratios occurred between genders for any of the cultures. This suggests that the causes of the gender differences in trace element levels observed among the Kitoi are metabolic rather than dietary.

This study's secondary goal of examining dietary differences due to status appears overly optimistic, in light of the small sample size and the lack of data concerning associated burial material for the individuals examined as well as the evidence of significant diagenetic alteration of their trace element levels. Interpreting the presence of social stratification exclusively on the basis of bone chemistry has not previously been attempted, perhaps for good reason. Any such interpretation requires the acceptance of an assumption -- for example, that dietary differences in a stratified society will result in a greater variation and wider range of δ values and trace element levels -- that has neither been tested nor documented quantitatively. Certain statistical measures, such as the CV, which are usually capable of illustrating ranges of variation (and are thus useful in studies of status) can not be directly applied to interval scale data such as δ values, which are based on an arbitrary zero point (Ambrose, 1993). The CV may also be inappropriate for examining trace element data as variance in elemental levels has been documented to decrease with length of interment (Blakely, 1989).

5.3 Summary

The differential effects of diagenesis on the trace element concentrations of both the human and faunal samples render their use in intersite dietary comparisons inappropriate, although the examination of intrasite variations are tentatively justified here on the assumption that diagenesis occurs at a consistent rate throughout the site.

The stable isotope data clearly distinguish between the Kitoi and the later cultures on the basis of both nitrogen and carbon. The Kitoi sample exhibits significantly higher δ^{13}C and δ^{15}N values than the samples from the later cultures. The consumption of fish and seal may have resulted in the higher δ^{15}N values. The high δ^{13}C values among the

Kitoi may be partially attributed to the consumption of cedar nuts. As the nuts were the only botanical specimens analyzed in this study, it remains to be determined if any other flora in the region have similarly high $\delta^{13}C$ values.

No statistically significant differences due to gender were observed among the Isakovo/Serovo and Glazkovo samples. Among the Kitoi sample, male specimens have a significantly lower mean strontium level than female specimens. Assuming consistent and proportional post-depositional alteration, this observation may be attributed to dietary or metabolic differences between Kitoi males and females. For all three cultural samples, no estimation of dietary differences due to status could be made.

CHAPTER SIX -- CONCLUSIONS

6.1 Archaeometric Analyses of Diet -- An Assessment

With the application of stable isotope and trace element analysis of prehistoric human remains, archaeologists have achieved greater resolution in their study of the dietary patterns of prehistoric populations. Despite their apparent sophistication, the potential of such techniques to provide relevant information remains contingent on a number of factors. The foundation of every paleodietary study consists of two primary components -- the archaeological and ecological reconstruction of the "menu" (Bumsted, 1985) of dietary resources available to the subject population, and the determination of the chemical composition of each of these resources. The isotopic and elemental composition of many food items, particularly those of non-Western origin, has yet to be determined (Klepinger, 1984). Buikstra *et al.* (1989) noted that recent studies of the trace element composition of maize and nuts have often included species not likely utilized by prehistoric populations.

Archaeological studies must contend with the prospect that the prolonged interment of bone may have resulted in substantial diagenetic alteration of isotopic ratios (Ambrose & Norr, 1992) and elemental concentrations (Lambert *et al.*, 1989, 1990, 1991; Price *et al.*, 1992). While the integrity of collagen can be assessed by amino acid analysis and non-collagenous proteins readily removed during specimen preparation, the appropriate criteria for recognizing diagenetic alteration of bone mineral remain to be determined. Given the expected biological variation in paleodietary indicators such as strontium, it may be difficult to determine when biogenic concentrations have been altered by diagenesis or reinstated by specimen preparation techniques. After conducting a recent, comprehensive study of diagenesis, Radosevich (1993:313) conceded, in reference to interred bone, that: "... the direction, quantity, and predictability of changes in elemental contents are often random and haphazard." This classification of diagenetic effects as both "random and haphazard" improperly insinuates a certain futility in efforts to understand them. Admittedly, while many variables affecting elemental concentrations have been recognized and used to form the basis of numerous cautionary tales, the quantitative expression of each of these factors has yet to be comprehensively documented and presented. But, like other chemical and physical processes, the mechanisms of diagenesis can undoubtedly be understood and their effects predicted, given sufficient investigation and knowledge of burial conditions.

Even in the absence of diagenesis, the utility of trace element data in dietary interpretation has only been equivocally demonstrated. As noted by Klepinger (1990:516), archaeological hypotheses concerning dietary differences in prehistoric human populations do not involve extreme contrasts. The scale of variation in elemental concentrations that has been observed between the dietary extremes (e. g., exclusive herbivores and exclusive carnivores) can not be expected to occur between prehistoric populations. In addition, interpretative dilemmas arise when the trace elements selected as paleodietary indicators (e. g., Ba and Sr) do not exhibit congruent or explicable patterns.

6.2 Conclusion

In light of the above discussion, any effort to reconstruct the diet of the Neolithic inhabitants of the Angara Valley -- particularly one that involves the interpretation of trace element data -- must be considered premature pending the systematic collection of ecological and pedological data. The data presented in this thesis do permit the hypotheses proposed in Chapter One to be addressed. Hypothesis 1 -- that the Isakovo/Serovo consumed more terrestrial meat and less fish than the Kitoi and Glazkovo -- is at least partially repudiated. The δ values suggest that the Isakovo/Serovo had a diet similar to that of the Glazkovo, and trace element levels -- though altered by diagenesis -- generally did not distinguish between the two cultures. It is possible that the difference in $\delta^{15}N$ values between the Kitoi and the other cultures resulted from the consumption of more terrestrial meat and less fish on the part of the latter. The data in this thesis provide tentative support for Hypothesis 2 -- that, among the Isakovo/Serovo, gender and status were not variables affecting dietary intake. The effect of status could not be addressed directly, but the stable isotope data do not differentiate between the sexes for this culture. Hypothesis 3 -- that dietary variations attributable to gender and status occurred among the Kitoi and Glazkovo -- is not supported by the data. Again, while status could not be addressed, no gender differences in isotopic ratios are observed among the Kitoi or Glazkovo, and the elemental differences noted between Kitoi males and females may be attributed to metabolic rather than dietary factors. Goriunova & Vorob'eva's hypothesis of a general consistency in subsistence activity throughout the Baikal Neolithic is not corroborated by the documentation of differences in stable isotope ratios between the Kitoi and the two later cultures.

The data collected during this research do not support any of the currently available models of the Baikal Neolithic. The Isakovo/Serovo and Glazkovo exhibit similarities with one another and significant differences with the Kitoi. No differences in stable isotope ratios are observed between the Isakovo/Serovo and Glazkovo samples, indicating a consistency in diet among the populations that used Ust'-Ida as a cemetery over the course of approximately 1500 years. Trace element levels -- with the sole exception of barium -- are also similar between the two cultures at this site. The most notable implication here -- and one that partially corroborates Goriunova & Vorob'eva's (1986) hypothesis -- is that subsistence practices, as evidenced by diet, did not change significantly with the introduction of metal artifacts.

On the basis of $\delta^{15}N$ values, it appears that the Kitoi consumed a slightly greater proportion of seal and/or fish than the Isakovo/Serovo and the Glazkovo. The observed difference in $\delta^{13}C$ values between the Kitoi and the later cultures is more difficult to explain. The data from the analysis of the cedar nuts indicate that certain C_3 plants in this region may have relatively high $\delta^{13}C$ values. Greater consumption of these and any unidentified C_4 plants would have resulted in the elevated $\delta^{13}C$ values for the Kitoi.

As noted above, the stable isotope data can not separate individuals in any of the three cultures according to gender. The differences in Sr levels between Kitoi males and females, if not an effect of diagenesis, may reflect a greater intake of meat among the former and/or the metabolic retention of Sr during pregnancy and lactation among the latter. A more productive examination of the relationship between diet and status must await the procurement of necessary mortuary data.

6.3 Recommendations for Future Research

In light of the analysis presented here, a number of directions for future research into the diets of the prehistoric populations of Lake Baikal become readily apparent. The continuation of archaeometric studies of paleodiet in this area will require the determination of local isotopic and elemental baseline levels as well as the identification of the food resources utilized by local prehistoric foragers. Reconstruction of the entire menu available to the Neolithic inhabitants of Lake Baikal may be based on knowledge obtained by modern ecological studies of local resources, historic and ethnographic data on native land use, and standard archaeological techniques -- e. g., examination of faunal remains and floral residues from habitation sites, documentation of artifact types, and analysis of artifact usage. The archaeological component of such a research program, in particular, necessitates systematic recovery of artifacts and ecofacts, as well as a quantitative assessment and statistical analysis of their distribution and abundance.

Once the menu has been estimated for each locality, the isotopic ratios and elemental concentrations in each food item can then be measured, and any possible variation from their prehistoric counterparts (e. g., due to environmental changes, the burning of fossil fuels and other types of pollution, etc.) taken into account. These data are required to provide a foundation for any paleodietary research in this particular region.

This study has presented a preliminary assessment of dietary differences between and within the Neolithic cultures of the Angara Valley. Further investigations are necessary to confirm that the differences observed between the Kitoi from Lokomotiv and the Isakovo/Serovo and Glazkovo from Ust'-Ida reflect cultural rather than geographic differences. Geographic variability in diet must be assessed by comparing the isotopic and elemental composition of individuals representing a single culture from a number of different and dispersed burial sites. The analysis of faunal specimens from each site should be conducted to provide a foundation for inter-site comparisons (Katzenberg, 1984; Price *et al.*, 1985*a*). Finally, a more precise assessment of the relationship between diet and gender, age, and status within cultures requires the analysis of large, representative samples of individuals from these and other sites as well as the compilation of detailed information concerning quantity and type of associated grave goods, neither of which was available for examination in this study.

The results of this thesis suggest that stable isotope ratio analysis will provide reliable and readily interpretable data concerning the diet of the prehistoric inhabitants of the Angara Valley. On the other hand, the integrity and utility of the trace element data obtained in this study could not be adequately assessed but the initial results appear discouraging due to the extent of diagenetic alteration observed. Any further efforts along this latter line of investigation must incorporate a stringent sampling procedure, more intensive examination of the geochemical conditions during excavation, currently accepted methods of specimen preparation, and careful selection of analytical equipment. A number of methodological improvements to the study presented here become immediately evident in hindsight.

1) Bone samples selected for analysis should be taken from a large long bone. The choice of fibulae for this study was necessitated by the limited sample of bones available, but the thinness and frailty of this bone renders it more susceptible to diagenetic alteration and more difficult to clean by physical abrasion. It is recommended that future analytical specimens be taken from analogous midshaft sections of femora. The use of teeth -- which are more resistant to diagenetic processes than bone (Parker & Toots, 1980) -- for analysis should also be considered. In addition, the frequent occurrence of animal teeth as ornamental items in Neolithic graves provides a ready comparative faunal reference.

2) Soil samples should be taken from each excavated burial, at regular horizontal and vertical intervals (as described in Lambert *et al.*, 1984*a*). In the likely event that the bone samples are obtained from previously excavated individuals, a random or systematic sampling of the soil from the site of origin should be conducted. Determination of the elemental composition and pH of the burial environment may permit an estimation of the diagenetic effects.

3) At present, it appears that the specimen preparation technique presented by Price *et al.* (1992) -- and described earlier -- is most effective at counteracting diagenetic alteration and, specifically, most capable of reestablishing biogenic levels of barium. Due to the constant revision and improvement of preparation techniques, the choice of an appropriate procedure -- specifically, one that can be used consistently throughout the course of a paleodietary study that may span several years -- is both difficult and essential, as the adoption of a new methodology during the course of a study renders comparison of previous and subsequent data sets inappropriate. Regardless of the procedure chosen, it would be advisable to retain all the products of sample preparation -- including the loose soil in the medullary cavity, the deionized water and any acid used to soak and rinse specimens, and any scrapings and shavings removed during abrasive cleaning -- for analysis. In this manner, one could document, rather than simply infer, the relative quantity of major and trace elements removed at each stage of preparation.

4) While ICP-AES has become the instrumentation of choice for many researchers conducting paleodietary analyses (e. g., Klepinger *et al.*, 1986; Price *et al.*, 1992, Ezzo 1992*a*, 1992*b*) by virtue of its ability to measure simultaneously and accurately the concentration of multiple elements, the method is known to be susceptible to spectral interferences. Of particular relevance to bone analysis, high concentrations of calcium may have a significant effect on the emission lines of trace elements. Lee (1983) documented a number of discrepancies between the expected elemental values for the IAEA H-5 bone standard and those obtained through ICP-AES analysis. The ICP-AES produced inflated

values for Ca and Mg. While Zn did fall within the expected range, Ba and Sr unfortunately were not examined by Lee so it has not been determined how relevant this source of variation is to paleodietary studies. The values for Ba and Mg produced in this study for the H-5 bone standard fell outside the expected 95% confidence interval (Table 7.2). It is recommended that, if ICP-AES is used in future studies, a subset of specimens be subjected, for comparative purposes, to analysis using alternative instrumentation such as the more sensitive ICP mass spectrometer.

Of course, there remain many problematic issues inherent to trace element analysis that must be resolved by other researchers contributing to the body of elemental data. The relationship between dietary and biogenic bone concentrations for many elements is still not sufficiently understood and will be elucidated only by additional experimental studies such as those conducted by Price *et al.* (1986) and Klepinger (1990). A similar lack of knowledge and consensus remains concerning the relationship between the elemental composition of buried bone and adjacent soil. Fortunately, a wide range of recent studies (e. g., Whitmer *et al.*, 1989; Pate & Hutton, 1988; Pate *et al.*, 1989; Edward & Benfer, 1993) should provide the foundation for a database from which to form predictive models concerning the movement of elements between these two media.

Finally, while chemical analyses of bone may provide information on the diet of prehistoric individuals, such data do not necessarily provide an appropriate foundation for interpreting social organization and other aspects of prehistoric hunter-gatherer society. Paleodietary studies have typically assumed a positive correlation between status and meat consumption. While this assumption may be applicable to the majority of prehistoric agricultural societies, the absolute quantity of meat intake may be less indicative of status among hunter-gatherers than the quality (i. e. fat content) of that consumed (Speth, 1990)[1].

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[1] The comparison of $\delta^{13}C$ values in bone collagen and apatite may provide insight into relative fat consumption -- the intake of lipids should result in a relative decrease in the $\delta^{13}C$ value of bone apatite (see Krueger & Sullivan, 1984).

In certain societies, meat is not even considered a high-status food (Klepinger, 1984). On the other hand, the absence of statistically significant status or gender differences in isotopic and elemental values should not mislead archaeologists into assuming dietary homogeneity within prehistoric foraging populations. A number of factors may result in differential nutrient distribution within presumably egalitarian hunter-gatherer societies (Speth, 1988, 1990). For the purposes of reconstructing prehistoric social organization, the use of paleodietary data should remain in its secondary role behind the analysis of mortuary practices and burial content (e. g., O'Shea & Zvelebil, 1984; O'Shea, 1984). Although no evidence for dietary variability due to status was uncovered in this study, the general absence of gender differences implies that analogous status-dependent differences were likely minor within the cultures of the Baikal Neolithic.

While it is recognized that further examination of the Baikal ecosystem must be conducted in order to provide an appropriate framework in which to interpret paleodietary data, this study has presented sufficient evidence from which to infer that the Kitoi people subsisted on diets distinct from those of the cultures that succeeded them.

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Appendices

Table 7.1: Correlation Tables

correlation coefficient (r)
sample size (n)
probability (p)

$p \leq 0.05$ in **bold**

Glazkovo -- Spearman rank correlation coefficients

	Ba	Mg	Sr	Zn	Ca	P
Mg	0.086 6 0.872					
Sr	0.371 6 0.468	0.829 6 **0.042**				
Zn	0.486 6 0.329	0.429 6 0.397	0.600 6 0.208			
Ca	0.029 6 0.957	-0.543 6 0.266	-0.371 6 0.468	-0.771 6 0.072		
P	0.200 6 0.704	-0.029 6 0.957	-0.257 6 0.623	0.486 6 0.329	-0.600 6 0.208	
ash	-0.131 6 0.805	-0.655 6 0.158	-0.655 6 0.158	0.131 6 0.805	-0.131 6 0.805	0.655 6 0.158

Glazkovo -- Pearson correlation coefficients

	Ba	Mg	Sr	Zn	Ca	P
Mg	0.396 6 0.437					
Sr	0.661 6 0.153	0.940 6 **0.005**				
Zn	0.661 6 0.153	0.879 6 **0.021**	0.919 6 **0.010**			
Ca	-0.166 6 0.753	-0.773 6 0.071	-0.683 6 0.135	-0.818 6 **0.047**		
P	-0.040 6 0.939	-0.142 6 0.788	-0.229 6 0.663	0.157 6 0.766	-0.242 6 0.644	
ash	-0.251 6 0.631	-0.458 6 0.361	-0.531 6 0.278	-0.192 6 0.715	0.028 6 0.958	0.903 6 **0.014**

Table 7.1 cont'd: Correlation Tables

Isakovo/Serovo -- Spearman rank correlation coefficients

	Ba	Mg	Sr	Zn	Ca	P	$\delta^{13}C$	$\delta^{15}N$
Mg	-0.143 7 0.760							
Sr	-0.286 7 0.535	-0.214 7 0.645						
Zn	-0.429 7 0.337	0.786 7 **0.036**	0.214 7 0.645					
Ca	0.595 7 0.159	-0.667 7 0.102	-0.036 7 0.939	-0.883 7 **0.008**				
P	0.250 7 0.589	0.393 7 0.383	-0.714 7 0.071	0.036 7 0.939	-0.270 7 0.558			
$\delta^{13}C$	-0.054 7 0.908	-0.234 7 0.613	-0.523 7 0.229	-0.144 7 0.758	-0.246 7 0.596	0.595 7 0.159		
$\delta^{15}N$	-0.500 7 0.253	-0.536 7 0.215	0.536 7 0.215	-0.214 7 0.645	0.180 7 0.699	-0.464 7 0.294	-0.036 7 0.939	
ash	0.334 7 0.465	0.185 7 0.691	-0.964 7 **0.000**	-0.259 7 0.574	0.037 7 0.937	0.852 7 **0.015**	0.598 7 0.156	-0.482 7 0.274

Table 7.1 cont'd: Correlation Tables

Isakovo/Serovo -- Pearson correlation coefficients

	Ba	Mg	Sr	Zn	Ca	P	$\delta^{13}C$	$\delta^{15}N$
Mg	-0.108 7 0.817							
Sr	-0.313 7 0.494	-0.228 7 0.624						
Zn	-0.230 7 0.619	0.757 7 **0.049**	0.234 7 0.614					
Ca	0.482 7 0.274	-0.693 7 0.084	0.010 7 0.982	-0.733 7 0.061				
P	0.335 7 0.463	0.559 7 0.192	-0.802 7 **0.030**	0.274 7 0.552	-0.358 7 0.430			
$\delta^{13}C$	-0.195 7 0.675	-0.313 7 0.495	-0.615 7 0.141	-0.385 7 0.394	-0.079 7 0.866	0.316 7 0.489		
$\delta^{15}N$	-0.665 7 0.103	-0.545 7 0.206	0.349 7 0.443	-0.295 7 0.521	0.279 7 0.545	-0.587 7 0.166	0.264 7 0.567	
ash	0.582 7 0.170	0.371 7 0.413	-0.902 7 **0.005**	-0.132 7 0.777	0.033 7 0.944	0.854 7 **0.014**	0.255 7 0.581	-0.639 7 0.122

Table 7.1 cont'd: Correlation Tables

Ust'-Ida (Glazkovo and Isakovo/Serovo) -- Spearman rank correlation coefficients

	Ba	Mg	Sr	Zn	Ca	P
Mg	0.192 13 0.529					
Sr	0.407 13 0.168	0.434 13 0.138				
Zn	0.110 13 0.721	0.654 13 **0.015**	0.577 13 **0.039**			
Ca	0.212 13 0.487	-0.630 13 **0.021**	-0.220 13 0.470	-0.801 13 **0.001**		
P	0.006 13 0.986	0.231 13 0.448	-0.544 13 0.055	0.110 13 0.721	-0.327 13 0.275	
ash	0.179 13 0.559	-0.035 13 0.911	-0.581 13 **0.038**	-0.195 13 0.524	-0.041 13 0.895	0.697 13 **0.008**

Ust'-Ida (Glazkovo and Isakovo/Serovo) -- Pearson correlation coefficients

	Ba	Mg	Sr	Zn	Ca	P
Mg	0.119 13 0.700					
Sr	0.308 13 0.306	0.413 13 0.160				
Zn	0.198 13 0.518	0.819 13 **0.001**	0.613 13 **0.026**			
Ca	0.229 13 0.452	-0.697 13 **0.008**	-0.245 13 0.419	-0.679 13 **0.011**		
P	0.046 13 0.881	0.266 13 0.381	-0.593 13 **0.033**	0.179 13 0.558	-0.324 13 0.281	
ash	0.507 13 0.077	0.161 13 0.599	-0.483 13 0.094	-0.104 13 0.735	0.036 13 0.907	0.695 13 **0.008**

Table 7.1 cont'd: Correlation Tables

Kitoi --Spearman rank correlation coefficients

	Ba	Mg	Sr	Zn	Ca	P	Fe	Mn
Mg	-0.200 10 0.580							
Sr	0.309 10 0.385	-0.758 10 **0.011**						
Zn	0.212 10 0.556	-0.479 10 0.162	0.139 10 0.701					
Ca	0.079 10 0.829	0.079 10 0.829	-0.333 10 0.347	-0.091 10 0.803				
P	0.261 10 0.467	0.176 10 0.627	0.358 10 0.310	-0.479 10 0.162	-0.176 10 0.627			
Fe	0.626 9 0.071	-0.612 9 0.080	0.267 9 0.487	0.832 9 **0.005**	0.100 9 0.798	-0.245 9 0.525		
Mn	0.416 7 0.353	-0.843 7 **0.017**	0.821 7 **0.024**	0.299 7 0.516	0.155 7 0.740	0.157 7 0.736	0.430 7 0.335	
ash	-0.350 10 0.321	-0.467 10 0.173	0.376 10 0.284	0.357 10 0.311	-0.701 10 **0.024**	-0.195 10 0.590	0.116 9 0.767	0.203 7 0.663

Table 7.1 cont'd: Correlation Tables

Kitoi --Pearson correlation coefficients

	Ba	Mg	Sr	Zn	Ca	P	Fe	Mn
Mg	-0.199 10 0.582							
Sr	0.258 10 0.471	-0.641 10 **0.046**						
Zn	0.263 10 0.462	-0.281 10 0.433	0.132 10 0.715					
Ca	0.179 10 0.622	-0.022 10 0.953	-0.262 10 0.464	-0.063 10 0.862				
P	0.223 10 0.536	0.112 10 0.759	0.234 10 0.514	-0.382 10 0.277	-0.198 10 0.583			
Fe	0.597 9 0.090	-0.532 9 0.140	0.165 9 0.671	0.844 9 **0.004**	0.095 9 0.808	-0.088 9 0.822		
Mn	0.730 7 **0.062**	-0.789 7 **0.035**	0.733 7 0.061	0.174 7 0.710	0.458 7 0.302	0.234 7 0.614	0.374 7 0.408	
ash	-0.396 10 0.257	-0.620 10 0.056	0.584 10 0.076	0.304 10 0.394	-0.425 10 0.221	-0.244 10 0.497	0.116 9 0.767	0.105 7 0.823

Table 7.2: H-5 Animal Bone Reference Values
(Mg, Ca, and P in %, others in ppm; * detection limit)
** published by International Atomic Energy Agency (from Link, 1990: Table 8)

	Ba	Fe	Mg	Sr	Zn	Ca	P
observed	105	34*	0.371	102	93	21.6	9.8
mean**	79	79	0.355	96	89	21.2	10.2
range** (± 2 s. d.)	67 92	73 85	0.346 0.364	88 105	84 95	20.4 22.0	9.3 11.0